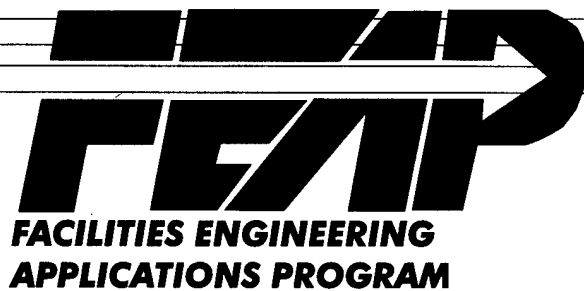


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January 1998



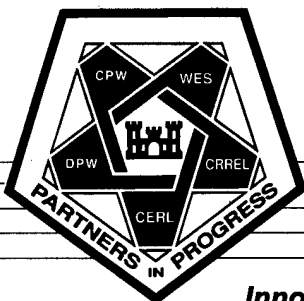
**TECHNICAL  
REPORT**

# Evaluation and Demonstration of an Advanced Electromagnetic System for Nonintrusive Underground Surveys

by  
Paul H. Nielsen  
U.S. Army Construction Engineering Research Laboratories  
Champaign, IL 61826-9005

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13. ABSTRACT (Maximum 200 words) This report documents field evaluations of the capabilities of GEM-1, an electromagnetic subsurface surveying instrument. GEM-1 was developed under the Small Business Innovative Research (SBIR) program as a tool for the expedient location of lost underground fuel storage tanks. GEM-1's characteristics allow its application to a variety of nonintrusive subsurface exploration applications. Evaluations conducted by USACERL included successful location and mapping of known and unknown underground storage tanks, pipes, a leach field, and a retired landfill. Searches for small buried pipes and small surface-placed ordnance were relatively unsuccessful, however, because the geometry and sensitivity of GEM-1 were designed for significantly larger targets. Many more applications of electromagnetic subsurface exploration will likely become common with the availability of GEM-300, a commercially produced device based on the concepts and capabilities tested in this program.					
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## Foreword

This study was conducted for the U.S. Army Center for Public Works under the Facilities Engineering Application Program (FEAP) Work Unit FL-FG5, "Location and Mapping of Underground Storage Tanks, Landfills, and Chemical Spills." The technical monitor was Malcolm McLeod, CECPW-FU-S.

The work was performed by the Engineering Division (FL-E) of the Facilities Technology Laboratory (FL), U.S. Army Construction Engineering Research Laboratories (USACERL). The USACERL principal investigator was Paul H. Nielsen. Larry M. Windingland is Acting Chief, CECER-FL-E, and Donald F. Fournier is Acting Operations Chief, CECER-FL. The USACERL technical editor was Gordon L. Cohen, Technical Information Team.

COL James A. Walter is Commander of USACERL and Dr. Michael J. O'Connor is Director.

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# 1 Introduction

## Background

An advanced lightweight electromagnetic surveying instrument for noninvasive exploration of the underground was developed for USACERL by Geophex, Ltd, of Raleigh, NC under a two-phase Small Business Innovative Research (SBIR) study (Geophex 1990a, 1990b, 1993). The GEM-1 (Figure 1) was developed primarily for the rapid location and mapping of underground storage tanks (USTs). USACERL owns the prototype and Geophex has continued with the development of the GEM-2 and the GEM-3, which uses a circular sensor geometry. GEM-2 has been licensed for commercial development. The GEM-1 design is based on an earlier system that Geophex built for the Navy—a much larger helicopter-towed version for topological surveys of the ocean floor.

The GEM-1 is not an electromagnetic system in which a target changes the resonant frequency of a coil system. The principles of operation are essentially frequency-independent, with operating frequencies determined mainly by soil properties.

The prototype instrument is self-contained and can store data from up to 1100 points. A typical survey is conducted by taking data at points on a two-dimensional grid covering the area of interest. The resulting data file can be processed on a

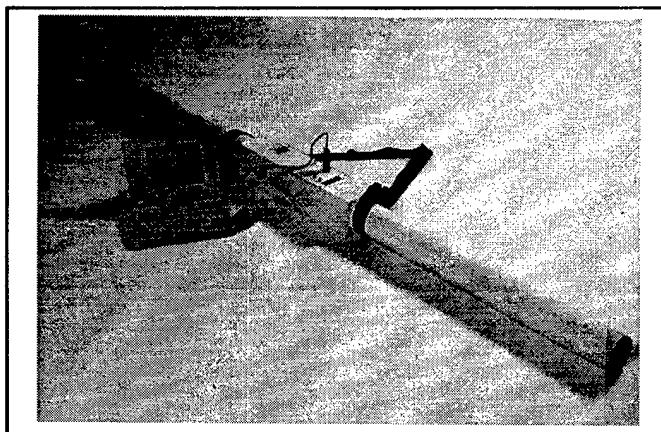


Figure 1. GEM-1 prototype electromagnetic profiling system.

desktop computer for interpretation using contour or surface plots. The variations in data recorded by the instrument result from differences of the electromagnetic properties of the soil or surrounding media, within the instrument's zone of influence. Originally designed for detecting metal USTs, the GEM-1 detects any phenomena producing a measurable change in the pertinent electrical properties. Potential additional applications include location and mapping of leach fields, hazardous/toxic waste dumps, unexploded ordnance, and buried landfills. The instrument's multifrequency capability may be used to derive depth information and absolute values of the earth's electrical properties. The technology is seen as an economical supplement to existing search tools such as magnetometers and ground-penetrating radar.

## Objective

The objective of this study was to evaluate and demonstrate the capabilities of the GEM-1 advanced electromagnetic profiling system for a variety of subsurface exploration applications and development of expedient surveying techniques.

## Approach

A wide variety of demonstration applications and study sites for this effort, within the scope of funding available, were identified and surveyed using the GEM-1. Fort Riley, KS was actively identifying USTs for removal and had a number of different situations: suspected lost tanks, fiberglass tanks, and possible nondocumented removals. Landfill locations selected for study at Fort Hood, TX and Fort Carson, CO were probably typical of those at military installations: all of those examined had been retired more than 20 years earlier. In addition to these FEAP-funded demonstrations, a Formerly Used Defense Site (FUDS) funded search for lost USTs was conducted at former Nike anti-aircraft sites in the Chicago metropolitan area. Other miscellaneous experimental applications were also addressed whenever such an opportunity occurred. The development of software macros reduced computer data processing to a small percentage of that previously required, resulting in a rapid and economical surveying capability.

## Scope

The demonstration subjects included: a specially prepared USACERL test area, UST sites, a natural gas pipeline, a metal culvert, part of an old cemetery, landfills and some residential applications. All of the surveys reported were conducted with the laboratory prototype (GEM-1). The features and capabilities of the commercial versions are to be slightly different, but the principles of operation remain unchanged. Geophex demonstrated GEM-2 on part of the FUDS study.

## Mode of Technology Transfer

Demonstrations of the GEM-1 can be arranged by contacting USACERL. The technical point of contact is Paul Nielsen, 217-373-7243. Geophex, Ltd., will conduct electromagnetic surveys with the GEM-2 on contract as part of their line of geophysical services. A commercial version of the instrument, GEM-300, is available from Geophysical Survey Systems, Inc., for \$13,900. Additional technology transfer information will be included in a FEAP Ad Flyer and FEAP User Guide.

## 2 Instrument Operation

### Data Collection and Storage

The GEM-1 is a lightweight (approximately 10 lb\*), digital, multifrequency electromagnetic system designed for location and mapping of subsurface features. This prototype instrument is provided with a shoulder strap and is carried waist-high during measurements. A radiating coil transmits an electromagnetic field that penetrates the earth. This transmitted field induces current flow in the earth, and this flow has its own field. A receiving coil measures this field. Since the direct transmitted field would overwhelm this much smaller reradiated field the system uses a "bucking" or pick-up coil to cancel the direct transmitted signal. The system does not rely upon resonant circuits for its operation as do conventional metal detectors. The GEM-1 is designed to make measurements at three frequencies, 800 Hz, 3200 Hz and 9600 Hz. The magnitude of the current flow in the subsurface and the resulting field measured by the instrument depends primarily upon the electrical conductivity structure of the materials within the subsurface. Materials with high conductivity will have high induced currents and large associated readings. Depth of penetration is a function of the conductivity structure and the transmitted frequency. Lower frequencies are associated with greater penetration. The conductivity of average soils differs from that of metals by a factor of approximately 8 to 9 orders of magnitude,\*\* but average soils differ from nonconducting materials such as fiberglass by only about 7 orders of magnitude. The difference in conductivity between nonconducting materials and poorly conducting soils is even lower. Therefore, a fiberglass UST would be more difficult to locate with GEM-1 than a metal tank.

The data measured by the GEM-1 is stored in the instrument as each frequency in turn is radiated and the ratio of the transmitted and received fields are computed, both in phase and quadrature components. These ratios are the basis for interpretation.

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1 lb = 0.453 kg.

\*\*

Martin B. Kraichman, *Handbook of Electromagnetic Propagation in Conducting Media*, NAVMAT P-2302, Headquarters Naval Material Command, 1970, Government Printing Office, p. A-2

## Survey Method

The GEM-1 instrument can be used in a manual mode by conducting a rough scanning of an area and observing data values at measurement points, but the full mapping capability of the instrument is only possible by computerized analysis of the data after conducting an organized survey. Such a survey normally consists of laying out a two dimensional grid of measurement points over the search area. Optimum grid spacing is a factor of target size and time/funds available. Most grid spacings used for the studies were either 5 ft\* or 10 ft. Because the instrument is sensitive to electrically conductive objects within its field of influence, the survey area should avoid known electrical conductors as much as possible since their signatures may unnecessarily complicate data interpretation. Conducting the survey consists of positioning the instrument over the points of the grid and recording the measurements at each of these points by pushing a button. Since the instrument automatically cycles through each of its three frequencies at each measurement point and records both the in-phase and quadrature data, there will be six possible plots for each survey.

## Data Analysis

The instrument stores the data in an ASCII file for downloading into a personal computer for analysis. Typical computer analysis consists of spreadsheet processing of the data file to produce individual frequency files with the grid information. Surface contour and/or contour plot representations of the data are then made with a plotting program. An optional program (Trend) was furnished with the instrument. This program is designed to reduce effects of instrument drift. Because a typical object of a search produces a discontinuity in the data field and because the GEM-1 does not measure absolute values, such gradual effects are usually of little significance. The spreadsheet processing is necessary to separate the data (both in terms of frequency and in-phase or quadrature) and to arrange it in a format usable by the plotting software.

## Macro Development

The GEM-1 ASCII data file consists of six columns or data sets (three frequencies, in-phase and quadrature for each) of numbers, each identified with a data point number. The plotting program, Golden Software Surfer for Windows 5.0, requires

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\* 1 ft = 0.305 m; 1 in. = 25.4 mm.

that the data be separated according to frequency and phase and arranged in rows and columns to match the measurement point locations. This data separation is accomplished using a spreadsheet program (Parsons Procalc or Lotus 1-2-3). The generation of surface or contour plots from the raw data requires a large number of sequential entries for both spreadsheet and plotter program operations. These entries essentially repeat for each of the six data sets and are quite similar for any data differing primarily in the grid dimensions. All three of the software programs have associated capabilities to run macros that can be programmed to pause for data entry and automatically process sequential keystrokes. A macro for the Procalc spreadsheet program was developed by USACERL to automatically sort the six sets of data into a proper grid format for Surfer and was also modified to use with Lotus 1-2-3. An available macro\* to automatically create surface plots from these data grids. These macros have reduced typical computer processing time required to produce surface plots from all six sets of data from approximately 2 hours to less than 10 minutes. While these particular macros are useful for the GEM-1 data and the particular software used, similar expedited data processing should be expected to be furnished with any commercial instrument.

### **Duration of Field Charging**

The use of dc-dc converters operating from 12-volt automobile systems to power a laptop computer and to recharge the GEM-1 battery pack has made possible field operations of 8 hours or more.

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\* "Automatically Creating Surfer For Windows Grids from Several Data Files," Golden Software, Inc., Newsletter, Vol 7, No. 1, Winter 1994-1995.



### 3 Experimental Applications

USACERL has used the GEM-1 for a variety of experimental applications, including:

- USACERL Test Area Studies, Champaign, IL
- Fort Riley, KS, UST Surveys
- Rural Nebraska Pipeline, Culvert and Cemetery
- Fort Hood, TX, Landfill Mapping and Characterization
- Residential Backyard - Illinois
- Fort Carson, CO, Landfill Mapping and Characterization
- Daykin, NE, P-47 Crash Site, summer and fall 1995
- Chicago, IL Park District, USTs at Nike antiaircraft missile sites
- Nebraska farm septic tank, tile field, and 1-inch pipe.

#### USACERL Test Area Studies

A laboratory study with a number of different target sizes and depth of burial was conducted over a period of time with differing frost conditions at USACERL at Champaign, IL.

The test bed was a 90 × 70 ft area in a relatively undisturbed plot on the USACERL grounds, prepared on 28 December 1993 by marking off grid points every 10 ft with wooden stakes. Metal samples were buried at a variety of depths as listed in Table

Table 1. EPS test samples.

Sample #	Description
1	18 x 18 x 1/8 in. aluminum sheet, buried 9 in.
2	18 x 18 x 1/8 in. aluminum sheet, buried 18 in.
3	3 ft length of rigid walled 1 in. diameter steel conduit, buried 12 in.
4	3 ft length of rigid walled 1 in. diameter steel conduit, buried 24 in.
5	1 ft length of rigid walled 1 in. steel conduit, buried 8 in.
6	1 ft length of rigid walled 1 in. steel conduit, buried 1 ft

1. Surveys were conducted on a number of different dates through the winter and early spring to evaluate the operation of the GEM-1 under differing soil and ground cover conditions. Soil conditions were wet to waterlogged during the study period.

The survey dates and associated conditions were as follows:

- 29 December 1993: Initial survey, soil relatively waterlogged, 28 °F\*, approximately 4 in. of snow and 4 in. frost depth
- 20 January 1994, 10 °F, approximately 4 in. of snow and a 1 to 2 ft frost depth
- 6 February 1994, 40 °F, approximately 1 ft of frost. Two sets of measurements were made; one with the instrument at the normal elevation and one with the instrument placed on the ground
- 1 April 1994, 65 °F, no frost, soil relatively wet. Two sets of measurements were made; one with the main axis of the instrument oriented east-west, one with the axis north-south

The results of these surveys are summarized in Figures 2 and 3. Figure 2 shows surface plots for all six sets (three frequencies with in-phase and quadrature) of data taken on 29 December 1993. Figure 3 shows the 3200 Hz data for all the surveys conducted on the different dates for this area during the period 29 December 1993 through 1 April 1994. The number codes on the plots include the date the data was taken (year, month, day), the frequency in Hertz of the data, if it is in-phase or quadrature and if the Trend program has been applied to the data to remove slowly varying components. Thus the designation 931229 3200qt indicates a survey on 29 December 1993, 3200 Hz quadrature processed by the Trend program.

Analysis of the data showed relatively insignificant variation due to frost and snow depth. Some additional sensitivity was gained by placing the instrument on the surface of the earth. With ground placement of the instrument there was a significant increase in background noise level. The locations of the aluminum plate samples are quite clear except in the higher frequency quadrature data, while only the shallower longer steel pipe was marginally detectible (mainly in the 800 and 3200 Hz quadrature data, not pictured). The smaller pipe sections and the deeply buried longer pipe could not be seen on these plots. Additional features which appear in the plots of the survey area are two fence posts for a snow fence at the left (north-east corner) of the plots and a negative-going "trench" that is apparently a single-phase direct-buried electric power line routed to an outlet on a post outside the survey area. The burial depth for this line is approximately 3 ft.

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\* °F = (°C x 1.8) + 32.

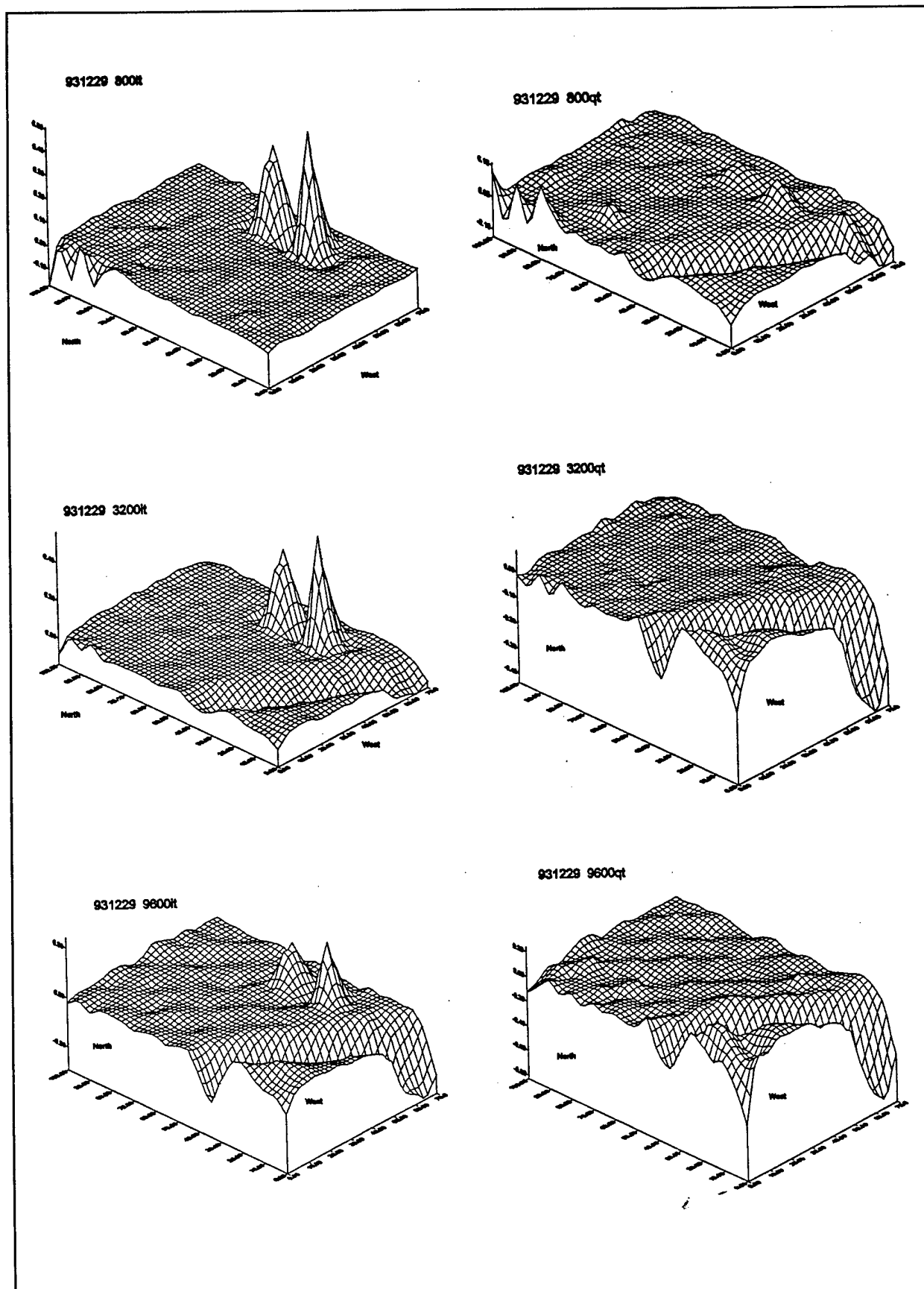


Figure 2. In-phase and quadrature data surface plots—USACERL Test Area, 29 December 1993.

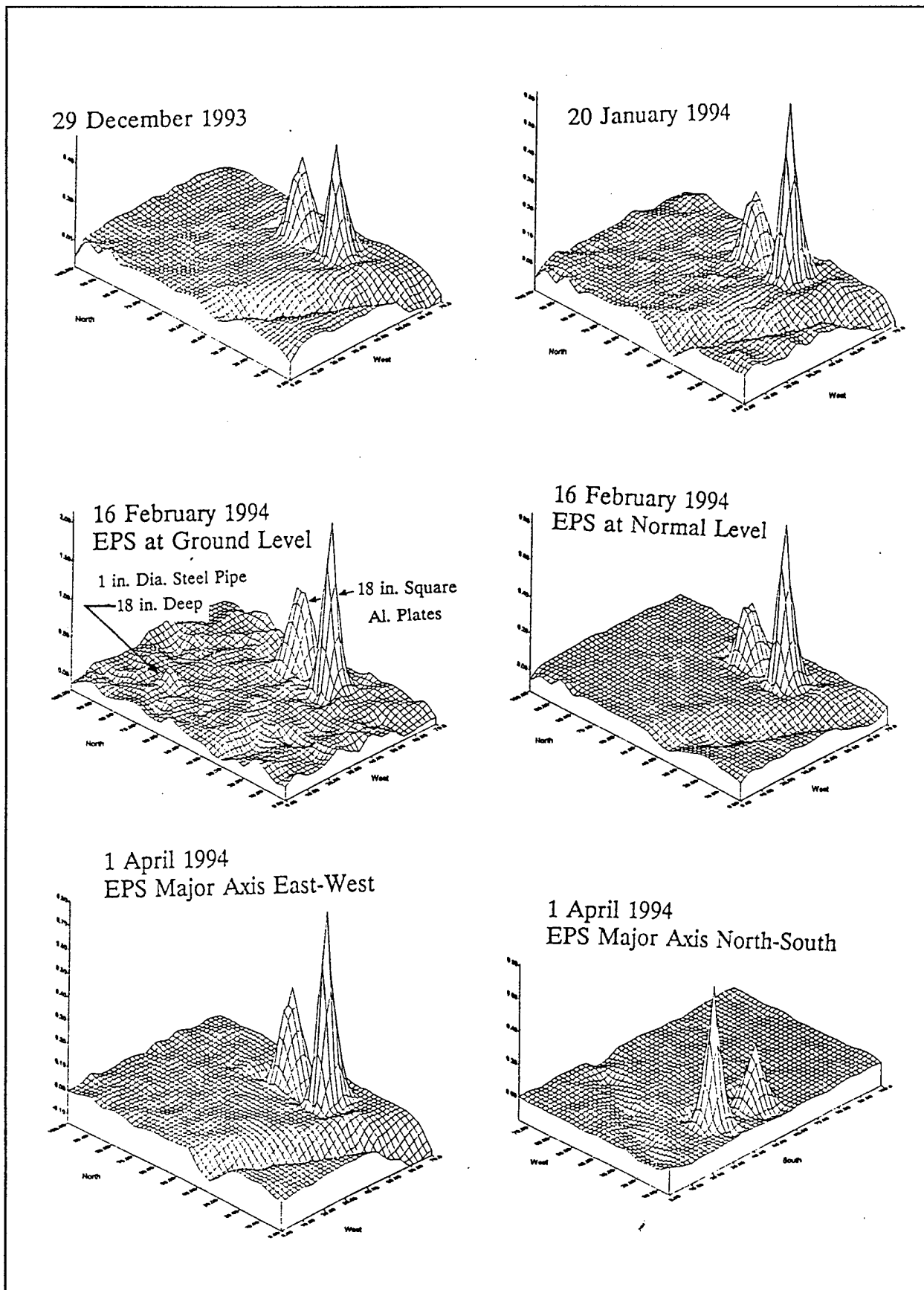


Figure 3. Surface plots of 3,200 Hz in-phase data—USACERL Test Area, 29 December 1993–1 April 1994.

## Fort Riley, KS, UST Surveys

USACERL was tasked to conduct a demonstration of the GEM-1 system for abandoned UST detection at Fort Riley, KS, to provide information for contracting for the removal of such tanks. The surveys to identify and locate buried tanks were conducted during 18-21 April 1994. The parts of the base surveyed were in the lower areas relatively near the Republican River. Most of the soil in the areas surveyed seemed to be black river bottom silt type of soil. Moisture conditions at that time were relatively dry. The 20 April 1994 *Daily Union* newspaper of Junction City, KS, reported a year to date precipitation of 2.84 in. compared to a normal of 6.61 in. Surveys were conducted with data points at 5 ft intervals using painted grid points at 10 ft intervals. The survey locations and results are described in the following paragraphs.

### ***Building 180***

Two searches were conducted around Building 180: one on the southwest side of the building for a possible tank associated with the abandoned boiler system located in the basement; the second in Area 2, north of the building, for a possible solvent tank. Both areas are in grass. This building had previously housed the base laundry.

The first search was conducted to the southwest of the building as shown as Area 1 in Figure 4. A 25 × 25 ft grid was marked and surveyed. The results of this survey were inconclusive, no definite "image" of a target was obtained in this area.

The second search was conducted in Area 2 (Figure 4) after it was learned that a 500 gallon solvent tank might have been associated with this building and that the tank's probable location was between the building and the street. Test wells in the area had shown traces of pollutants. The grid for this search was a 70 × 20 ft area starting 5 ft from the building. No effects were noted from a power line with wires at a 20-ft elevation or more that was parallel to the street near this area. The results of this survey are included as Figure 5. A definite image appears on the plots. Based on these results, base personnel explored this location and uncovered three tanks. The long axis of these tanks was vertical.

### ***Building 240***

A search was conducted for a suspected abandoned fuel oil tank associated with a retired heating system. The location was under an asphalt-surfaced parking lot southeast of the building. Arrangements were made to have metal storage racks, other metal objects and vehicles removed from the search area and a 35 × 40 ft

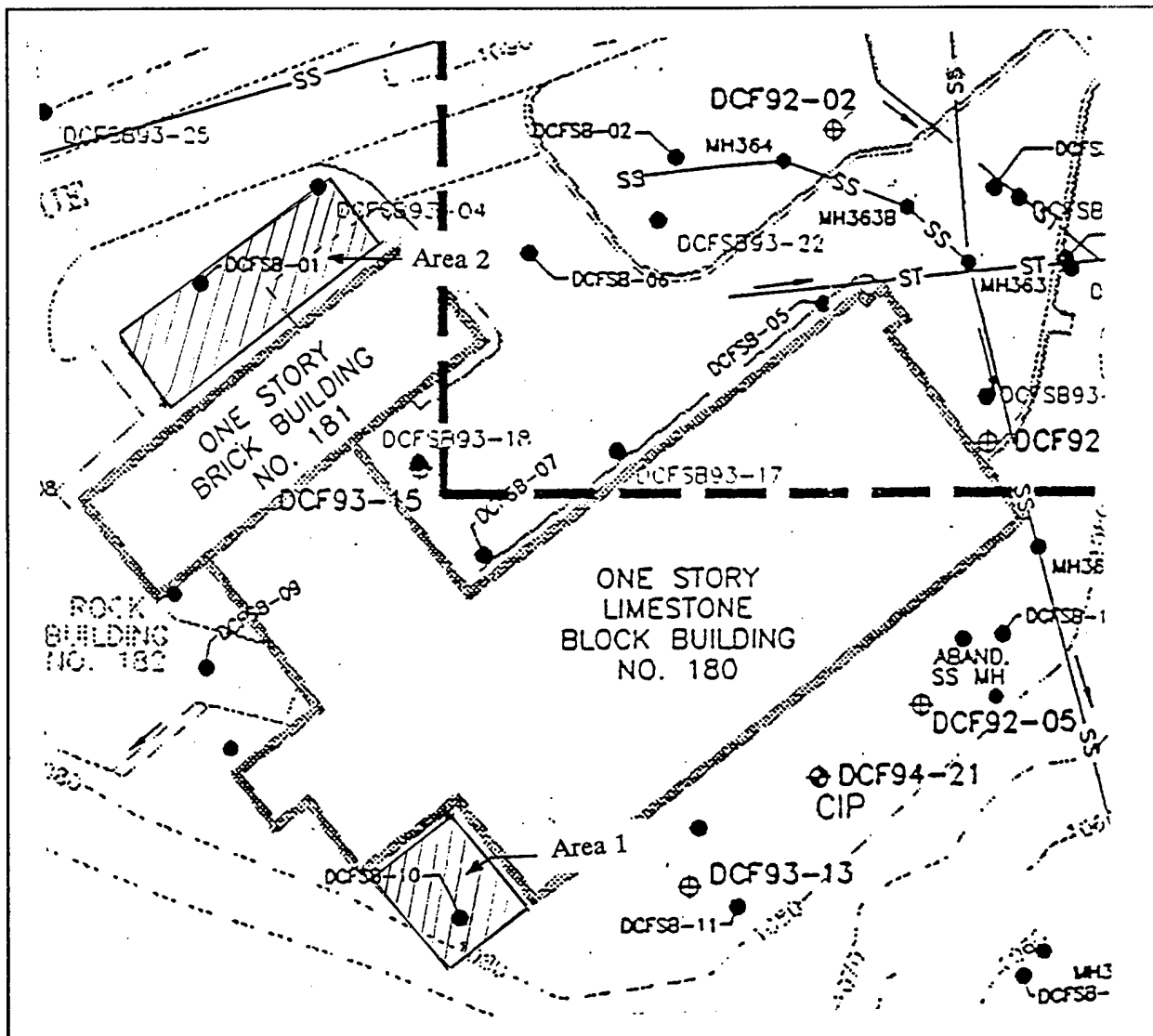


Figure 4. Building 180 with survey areas, Fort Riley, KS.

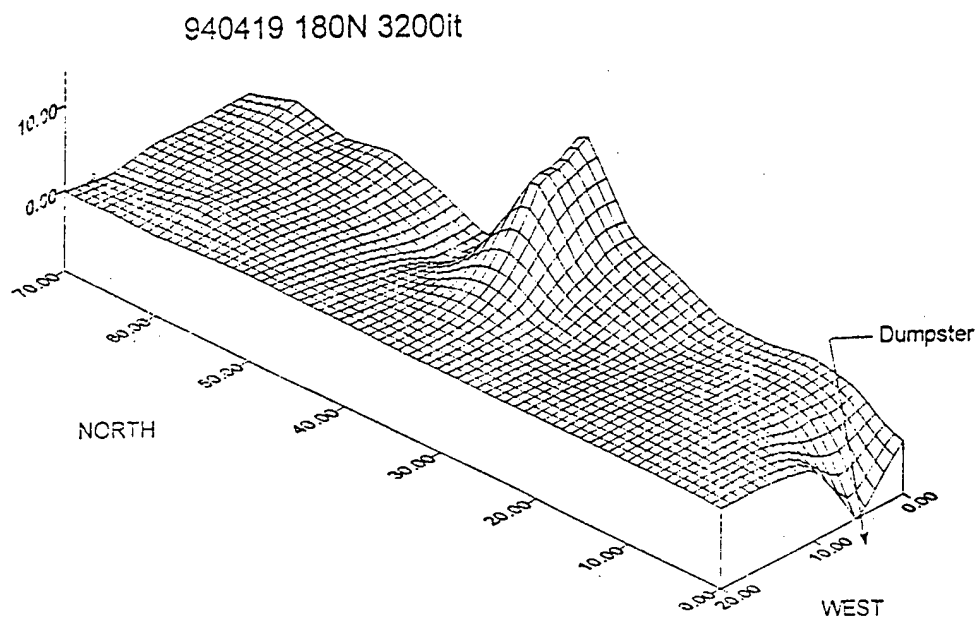
(north-south) grid was laid out. The search area was bounded on the north and west sides by Building 240. The results of this survey are plotted in Figure 6. A fairly large underground metal structure is indicated and is probably the suspected UST. Significant aboveground interfering metal structures were present adjacent to this search area.

### **Building 7958**

This search was conducted to evaluate the performance of the GEM-1 in imaging a 500-gallon fiberglass fuel tank that was possibly located under the parking lot. This location was an upland area away from the river bottom. The site drawings indicated its position in an unpaved area of this lot. A 40 x 35 ft grid was laid out on the paved parking lot. Unfortunately the south side of the search area was near



(a)



(b)

Figure 5. (a) Building 180 with tank locations marked, June 1994 and (b) Surface of area adjacent to Building 180, Fort Riley, KS, April 1994.

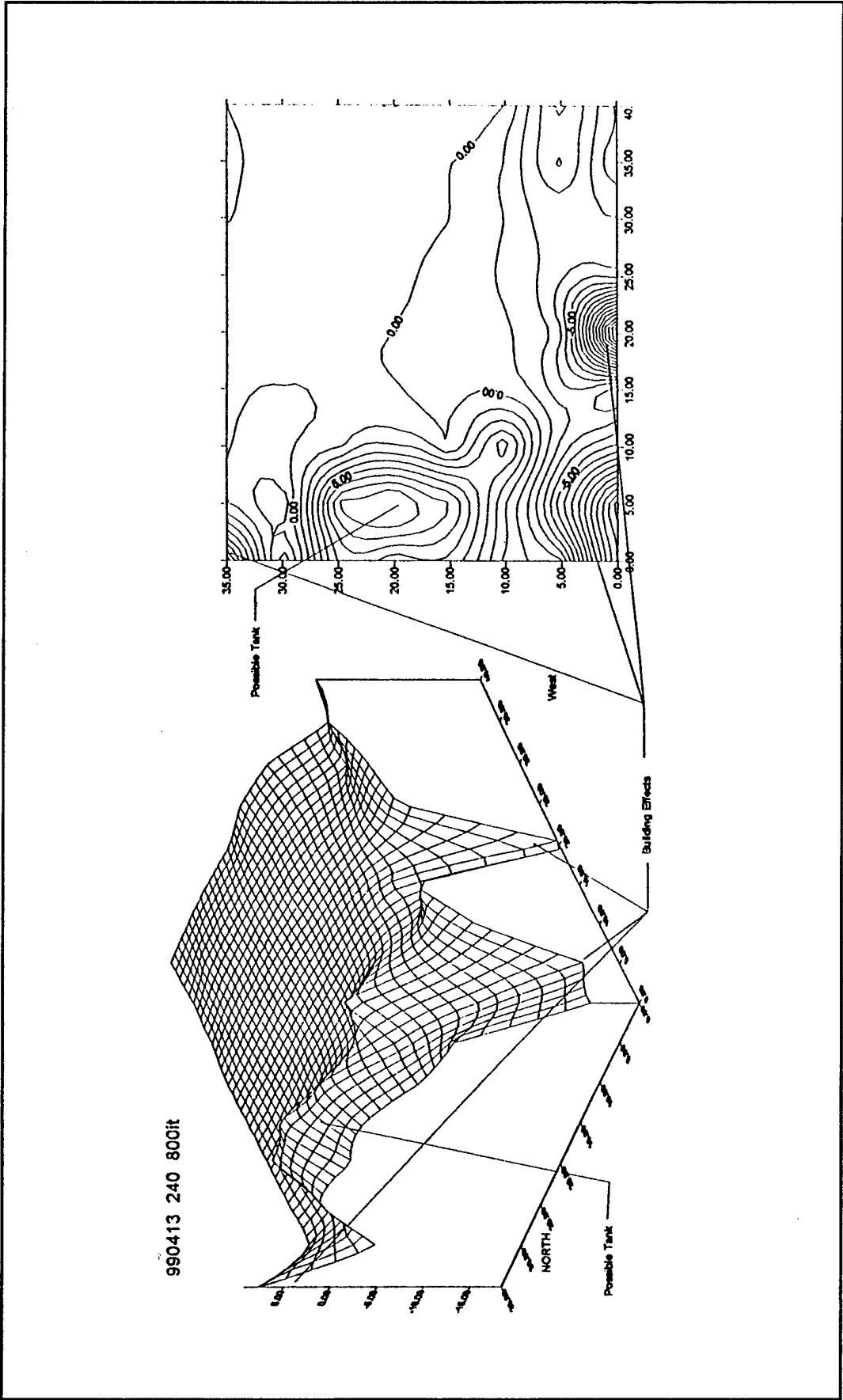


Figure 6. GEM-1 survey data, Fort Riley, KS, parking lot near Building 240.



a high chain link fence. The dip in the data on the north side indicates the presence of motor vehicles. Representative results are presented in Figure 7. No indications of a tank appear on this data. Either the tank is no longer there or evidence of it is not strong enough to appear on this data because of the nearby aboveground metal structures.

### Area 7350

The subjects of the surveys in this area were two large (30,000 gallon) storage tanks, one fiberglass and one steel, in known locations in a paved military vehicle refueling area. These locations were surveyed to provide data on known underground tanks and were also upland areas. Representative results are presented in

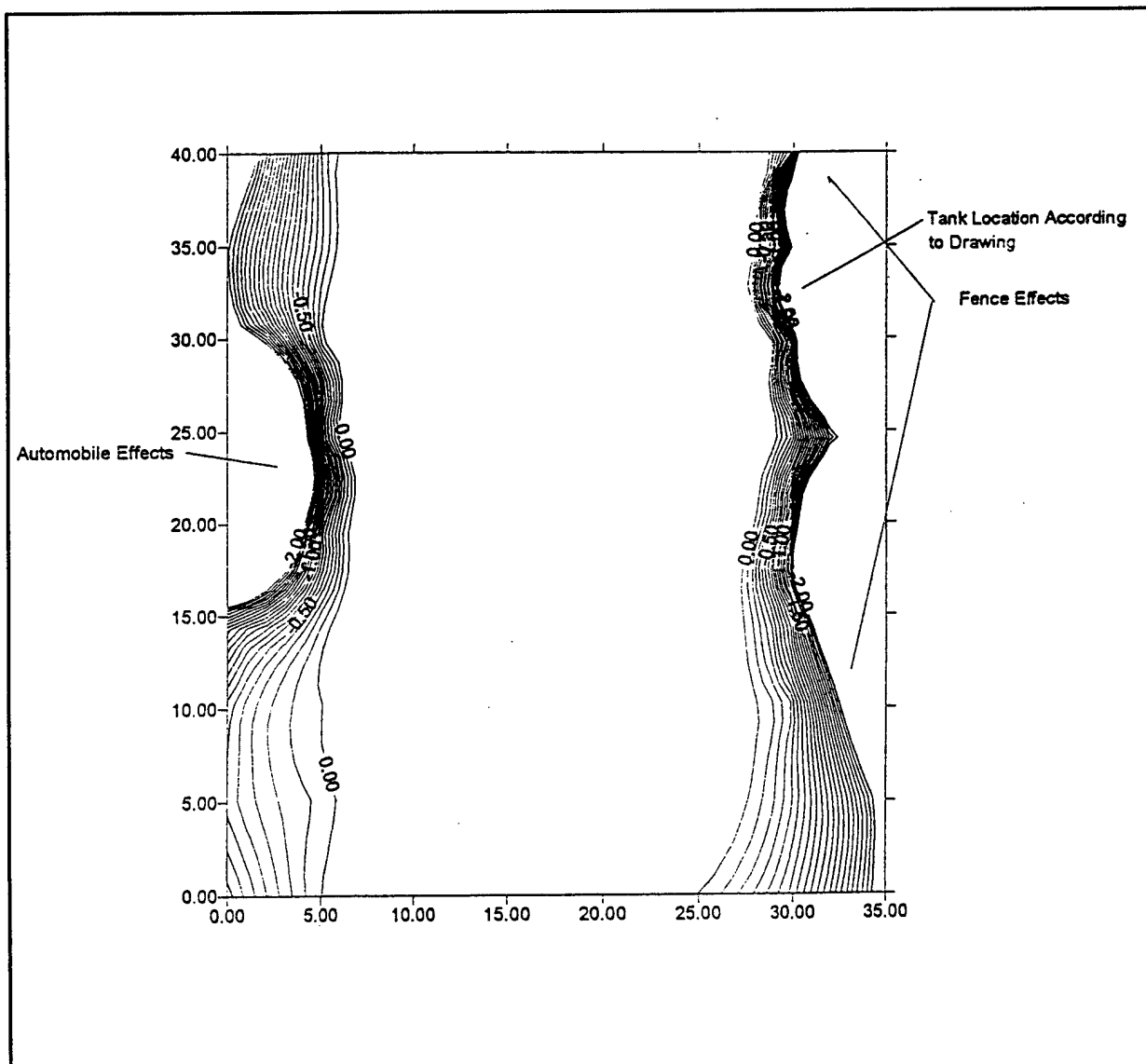


Figure 7. GEM-1 survey data, Fort Riley, KS, possible fiberglass UST.

Figure 8. A significant number of visible metallic structures are associated with the fiberglass tank. These include piping, manhole covers, etc. probably explaining the large number of images associated with this survey. A traffic island, consisting of 3-ft-tall vertical concrete-filled large-diameter metal pipes, produced a large disturbance in this data. The readings from this structure (in the middle north of the plot) appear to overwhelm the image from the tank.

### Rural Nebraska Pipeline, Culvert, and Cemetery

Three additional surveys were conducted in April 1994. Two of these surveys were conducted as a single traverse along gravel roads in rural Saline County, NE. Soil types in this area tend to be black loam. Moisture conditions had been relatively dry since the 1993 growing season, but approximately 1 in. of rain had fallen the night before the measurements were made.

One survey was conducted at a natural gas pipeline crossing. The pipeline was installed in 1982 and crosses the road at approximately an 85 degree angle. It is a 3 ft diameter steel pipe buried at least 6 ft or possibly as much as 10 ft. The road

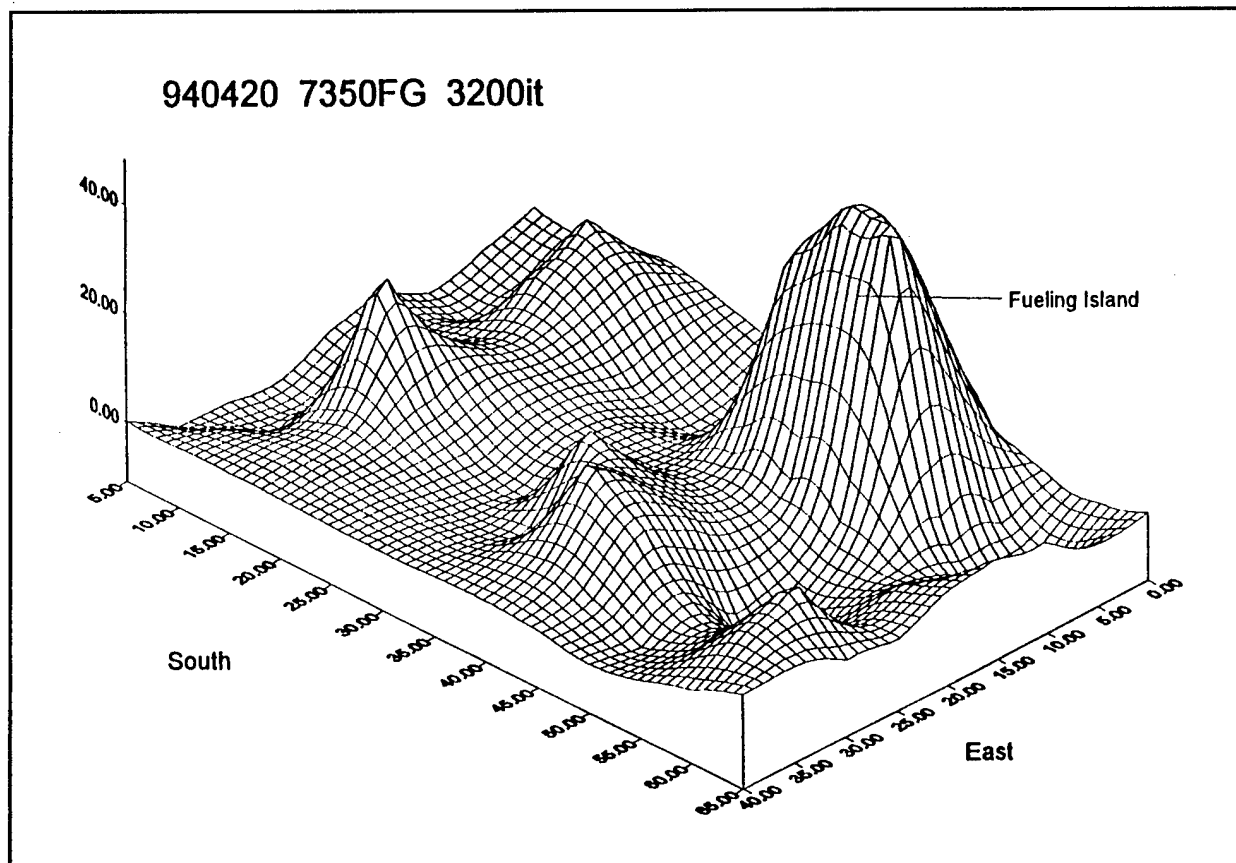


Figure 8. GEM-1 survey data, Fort Riley, KS, fueling area 7350.

crossings were made by boring under the roads and installing the pipe. No trench was made across the roads and no back filling was done at the crossing. An intermediate voltage 3-phase electrical transmission line with an average line elevation of approximately 20 ft was located parallel to the east side of the road. This power line did not seem to interfere with operation of the instrument. A single traverse of the pipeline from north to south on the road was made. Results for this survey are shown in Figure 9. The plots indicate the size and depth combination of this object are well within the detection range of the GEM-1.

A second survey was conducted as a single traverse of a 2 ft diameter steel culvert crossing beneath a gravel road at a right angle, buried 3 ft below the crown of the road. Two intermediate voltage electrical transmission lines, one on each side (both 3-phase systems with an average elevation of 20 ft) run parallel to the road. No interference from these lines was noted. In Figure 10, the results of this survey show that this object is also well within the detection range of the instrument.

A survey of part of a cemetery was also conducted in April 1994. Most of markers indicated burials previous to the mid-1930s. Results of this survey are shown in Figure 11. In general, the images roughly coincided with more expensive grave markers and it is probable that these are burials with metal caskets.

## Fort Hood Landfill Surveys

A research demonstration to investigate the response of the GEM-1 to covered landfills was conducted at Fort Hood, TX, on 15-18 August 1994 as a FEAP activity.

The characteristics of a landfill area as seen by an electromagnetic profiling system are likely to be relatively strong variations in the electrical conductivity profile. These variations are due to the diversity of materials typically found in a landfill. For instance, the image of a UST may be a relatively uniform mound, while the landfill image is likely to be a random arrangement of peaks and crevasses.

Data was taken at Fort Hood at a number of locations with the GEM-1 during the period 15-18 August 1994. The search locations on the main base are shown in Figure 12. Soils in this area tend to be thin and dry over limestone. Individual data sets are identified by the date the survey was conducted and an alphabet letter indicating the sequence in which the data for that day was taken. Compass directions describing path directions are approximate.

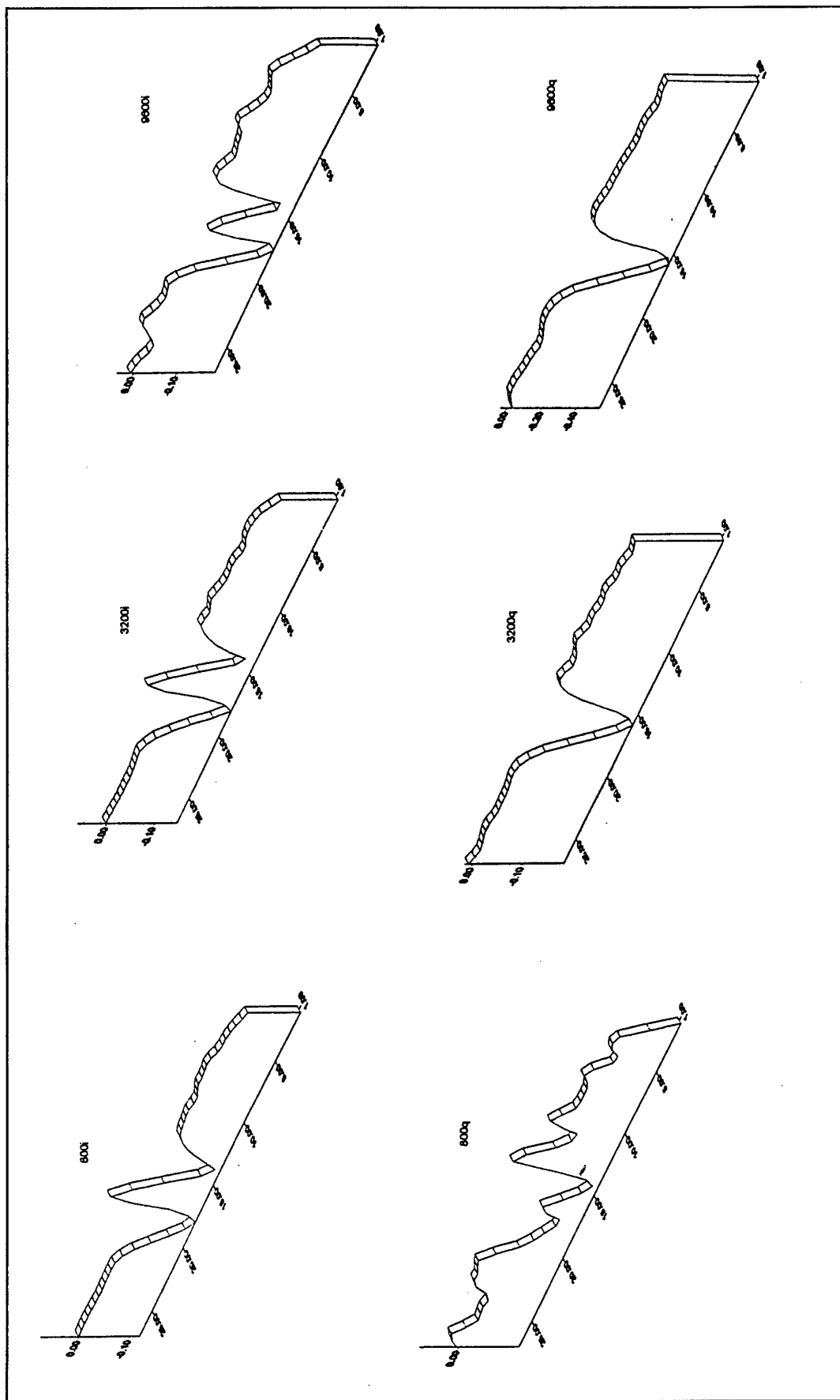


Figure 9. Traverse of a natural gas pipeline, 3 ft diameter.

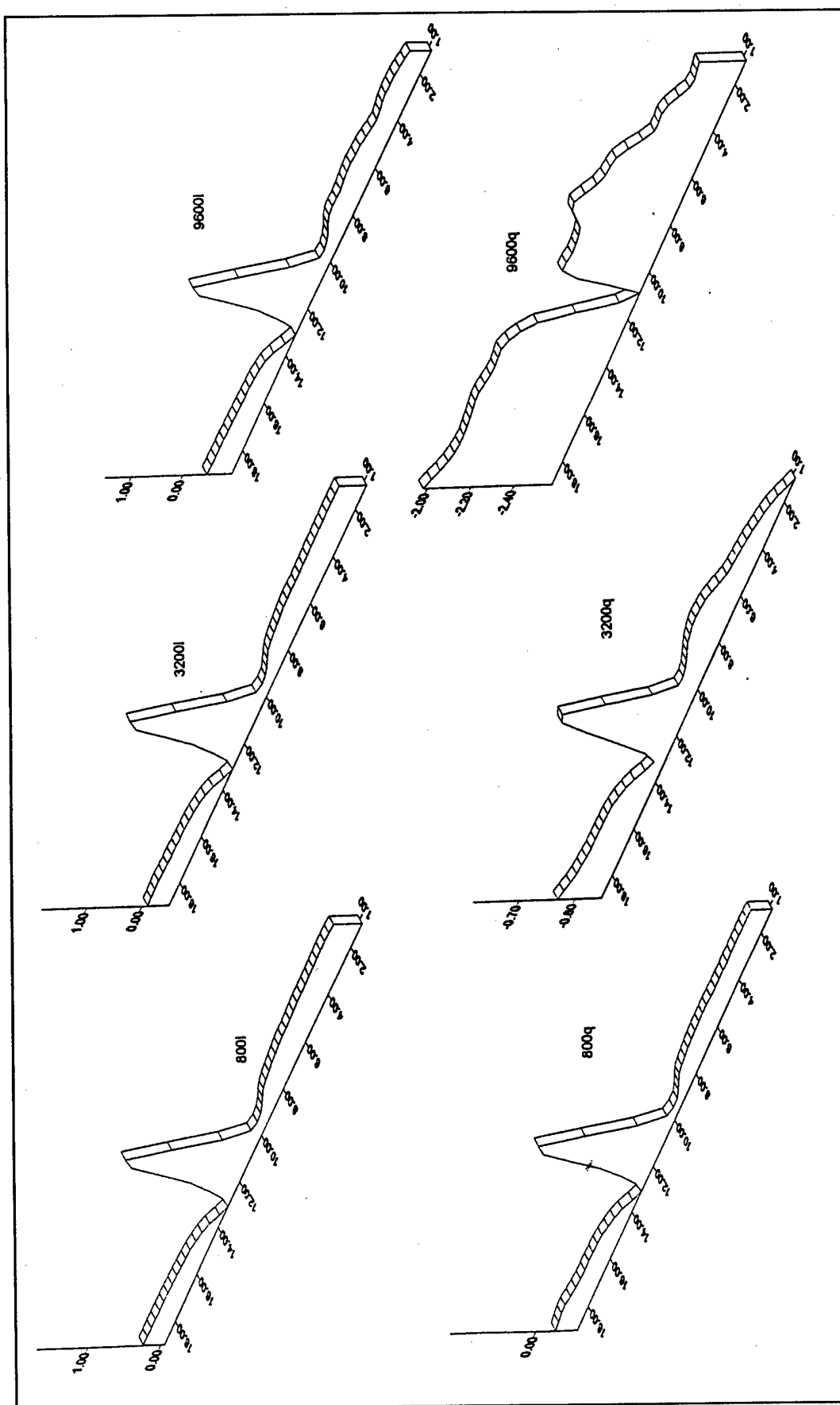


Figure 10. Traverse of a 2-ft diameter culvert.

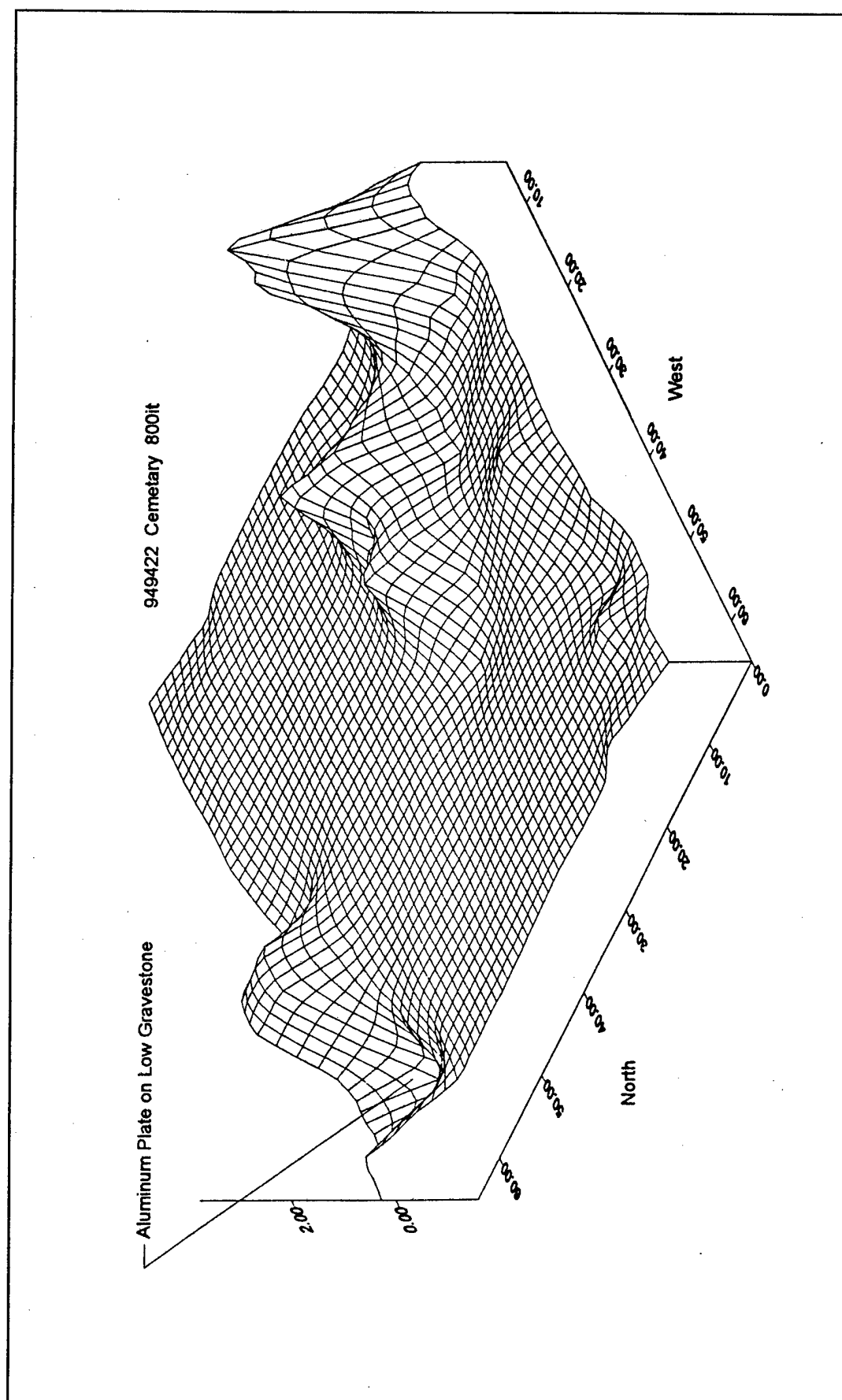
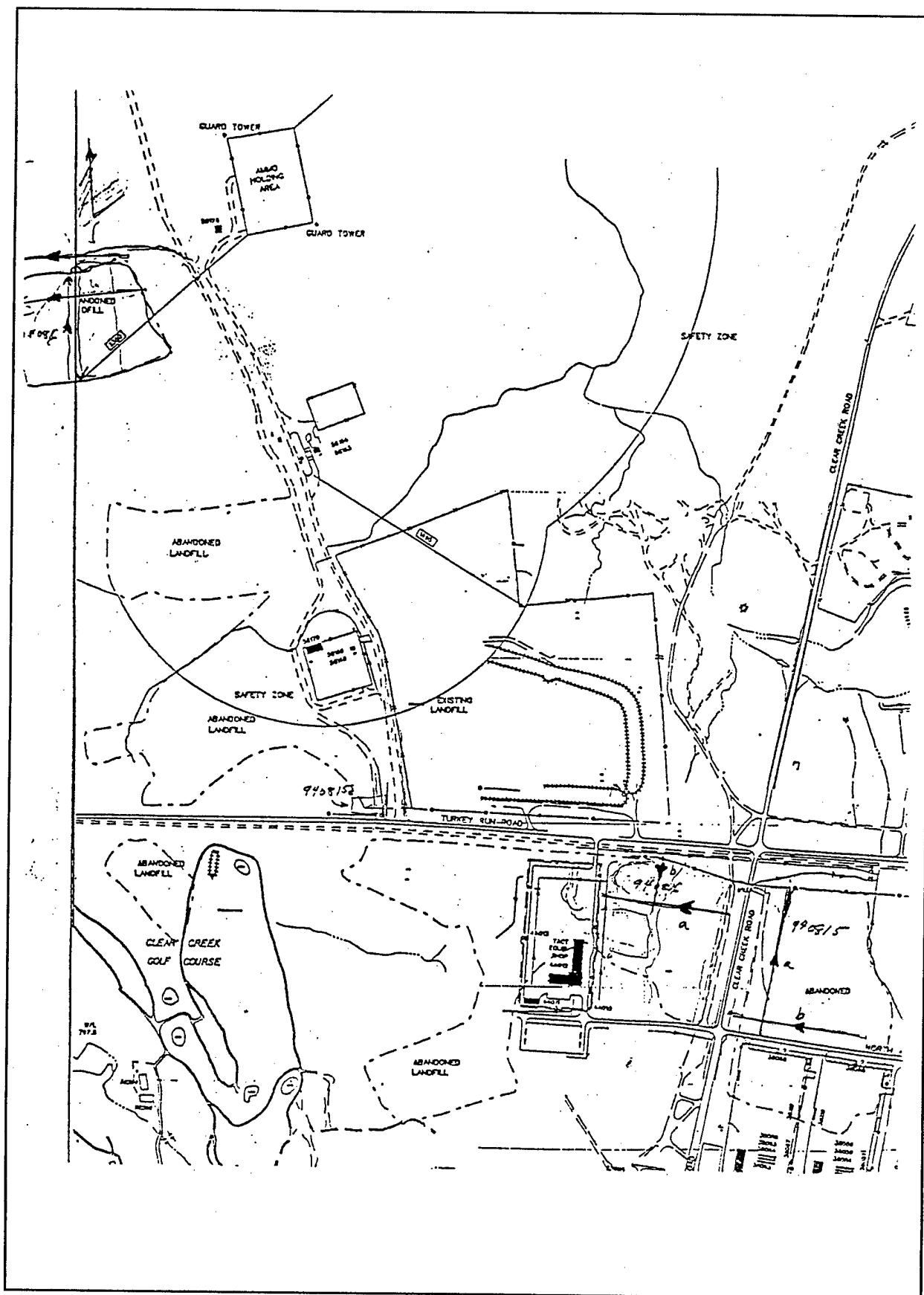


Figure 11. Rural Nebraska cemetery (pre-1935).



**Figure 12. Fort Hood main base landfill search areas.**

The Geophex GEM-1 EPS was designed primarily to locate USTs. Its physical dimensions and electrical characteristics were optimized for that application. The previously described UST searches were conducted by marking grid points with paint spots on the area to be surveyed and taking data at each point on the grid. Such a grid marking process becomes less practical as the search area becomes large and the object of the search does not need to be precisely located.

Two different procedures for expedient surveying were used at Fort Hood in addition to the grid marking procedure. The first, designed to rapidly obtain an idea of the extent of the landfill, consisted of taking data in straight paths across the search area. In general, data was taken in two or more sets (a set consisting of a single traverse), typically with the paths at right angles. Data points were every four steps—approximately 10 ft. The data was plotted using the same software used to produce the surface plots for the grid data. This results in an oblique view of a line of data. Figure 13 is a representative sample of data taken by this technique showing a relatively level reading outside the borders of the landfill and sharp variations over the landfill area.

The second approach consisted of an expedient grid layout procedure to map a portion of a landfill. This was done by establishing a baseline (approximately 250 ft long) and marking the ends of the baseline with fiberglass electric fence posts

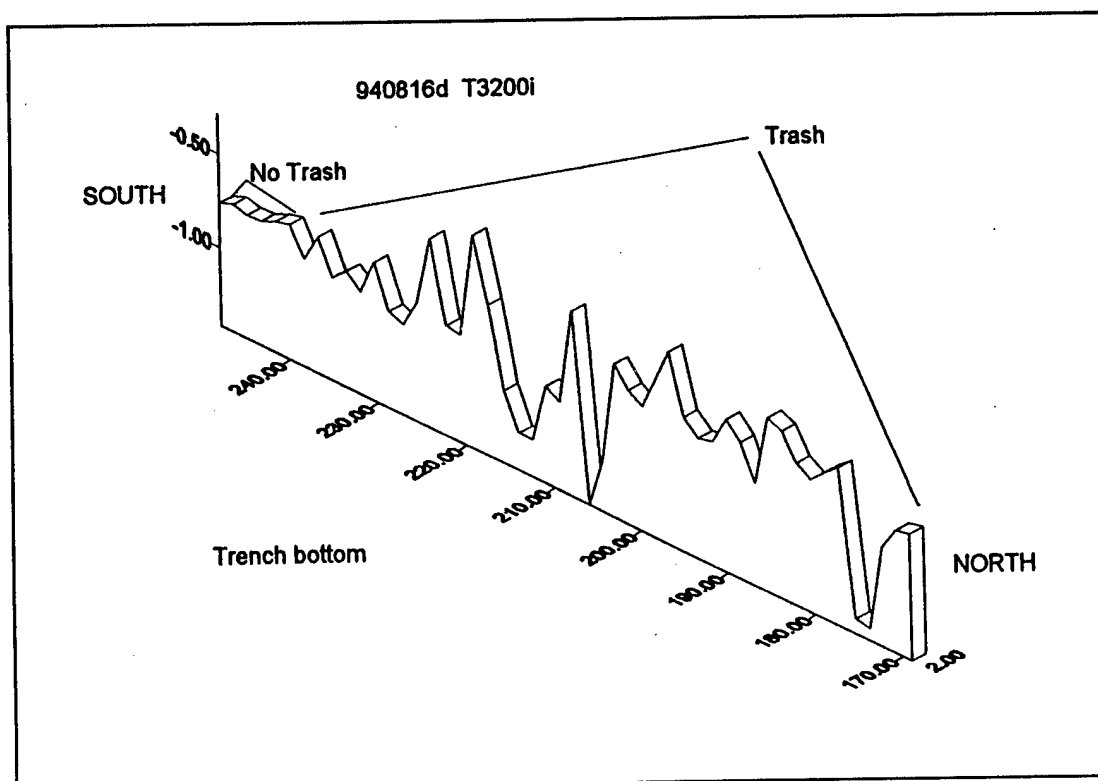


Figure 13. GEM-1 survey data, typical landfill traverse, Fort Hood, TX.



(approximately 0.5 in. in diameter and 3.5 ft long). Next, data were taken along the baseline by starting from one end and walking directly toward the marker at the other end of the baseline. Data was taken every four steps. After completion of the baseline measurements, the end markers were moved 10 ft and used for another line of data. While not as exact as a measured and marked survey, this technique produced a relatively good image of the extent of the landfill (Figure 14).

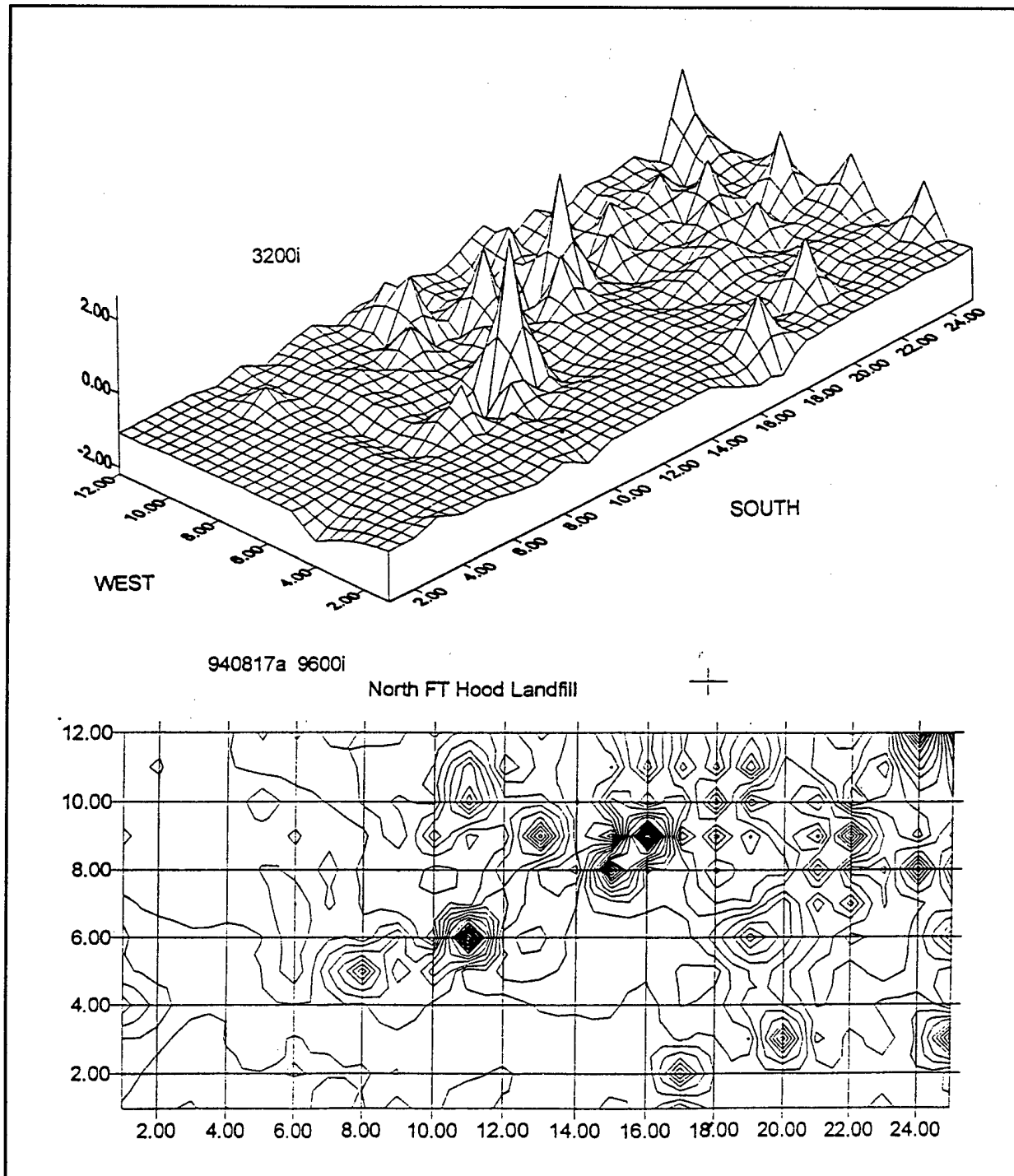


Figure 14. GEM-1 survey data, north Fort Hood abandoned landfill.

## Residential Back Yard Survey

A survey was conducted on 10 October 1994 in a residential back yard in Illinois to investigate the possible existence and location of a suspected abandoned underground fuel storage tank. The owner had discovered a buried copper pipe leading away from the house (which was built in the mid to late 1950s) while installing a drain tile around the house. Data was collected by measuring out the search area, placing two tapes at the ends and stepping off approximate 5 ft intervals. The results of this survey are shown in Figure 15. A probe indicated a solid object about 18 in. below the surface of the soil at the "image" location. A septic tank predating the city sewage connection is also present in the yard. The flat septic tank lid was found about 6 in. below the surface. It is probably concrete and may contain metal reinforcement. The house effects are aluminum framed windows. A burn pile consisting of ashes most likely from burning leaves and/or trash can be seen in the corner of the surveyed area. The current resident has not used the burn pile in the year he has lived there. Later excavation at the image location showed that the tank appeared to be a well rusted, metal container that can be best described as 55-gallon drum reduced to 1/3 its height with no top. The container was found about 12 to 18 in. below the surface.

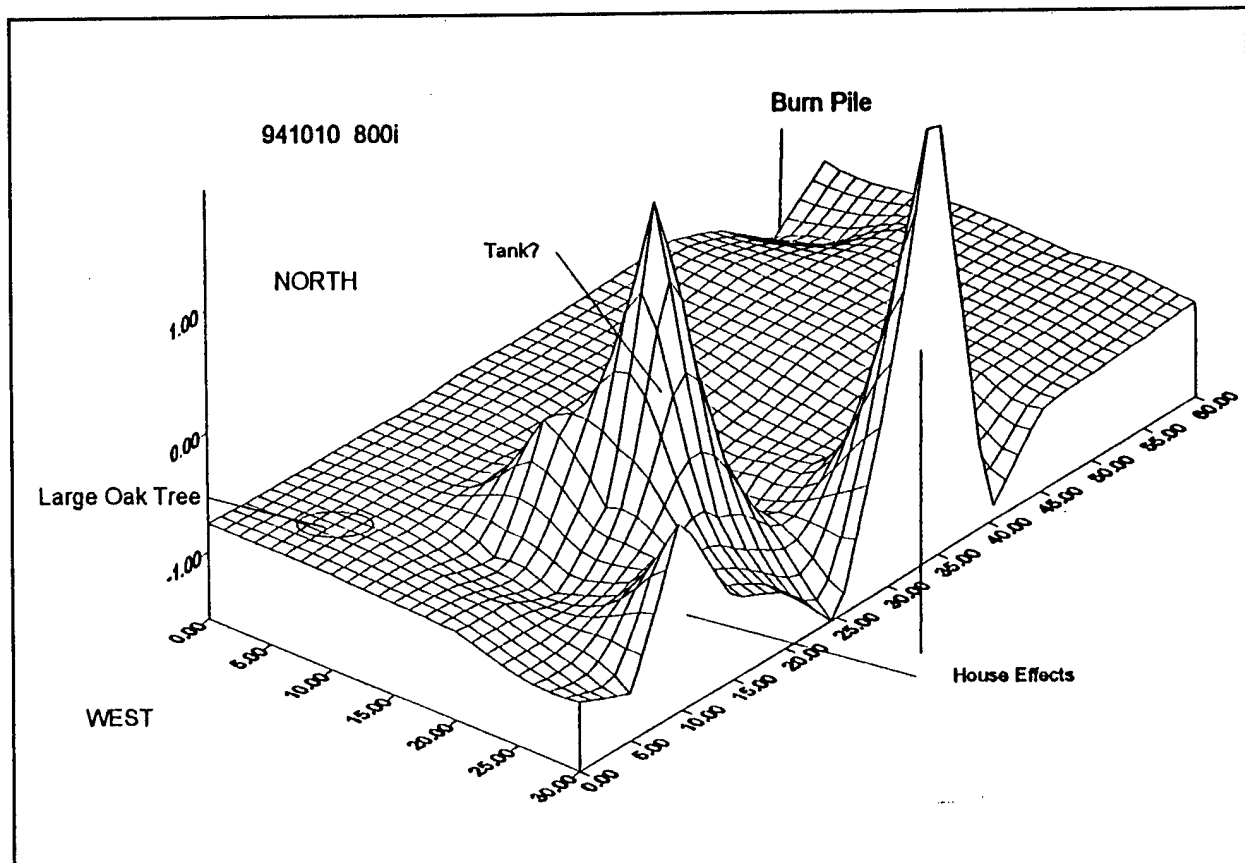


Figure 15. Residential back yard with suspected UST.

## Munitions Searches

On 1 March 1995, a representative from the Joint Task Force - Full Accounting and an engineer from the Naval Explosive Ordnance Disposal Technology Center visited USACERL to conduct munitions search tests with the GEM-1. The searches were conducted in a relatively clean 30 × 20 ft grassy area immediately to the north of the main USACERL complex. The history of the area is uncertain, but it appears to be relatively undisturbed with the possibility of some surface fill from the construction of the USACERL complex. The visible surface is a typical Illinois black loam. Earlier sweeps showed that there were no significant targets in this area. Five objects were placed on the ground in the test area. These were:

1. 60 mm mortar round
2. M904 fuse
3. Blue 3
4. Blue 29 (golf ball sized and shape)
5. 40 mm projectile.

The air temperature was 25 to 30 °F. The soil surface was damp. The first sweep was conducted from west to east with a 2.5 ft spacing between data points. The second was in the same direction with a 5 ft spacing. The third was from south to north with a 5 ft spacing.

Plots of the data indicate the presence of two of the larger of these munitions. The data is shown in Figure 16.

## Fort Carson Landfill Mapping and Characterization

USACERL conducted a FEAP demonstration consisting of landfill mapping and characterization with the GEM-1 for the Fort Carson, CO, Directorate of Environmental Compliance and Management on 26-29 June 1995. Most of the activities were associated with Landfill #5 which was in use from approximately the mid-1940s to the mid-1950s. Fort Carson was the last calvary base in the Army. Landfill #5 was located near the mule barns and base personnel expressed the opinion that it was likely that a significant portion of the landfill probably consisted of mule manure. The sketched map of the landfill and the associated search areas is given in Figure 17. The spring of 1995 had been unusually moist in the area and the landfill area was covered with flowering yellow sweet clover approximately 3 to 4 ft high, which somewhat impeded the collection of data. Soils in this area are quite sandy with a better quality soil used to cover the landfill. Both line and area

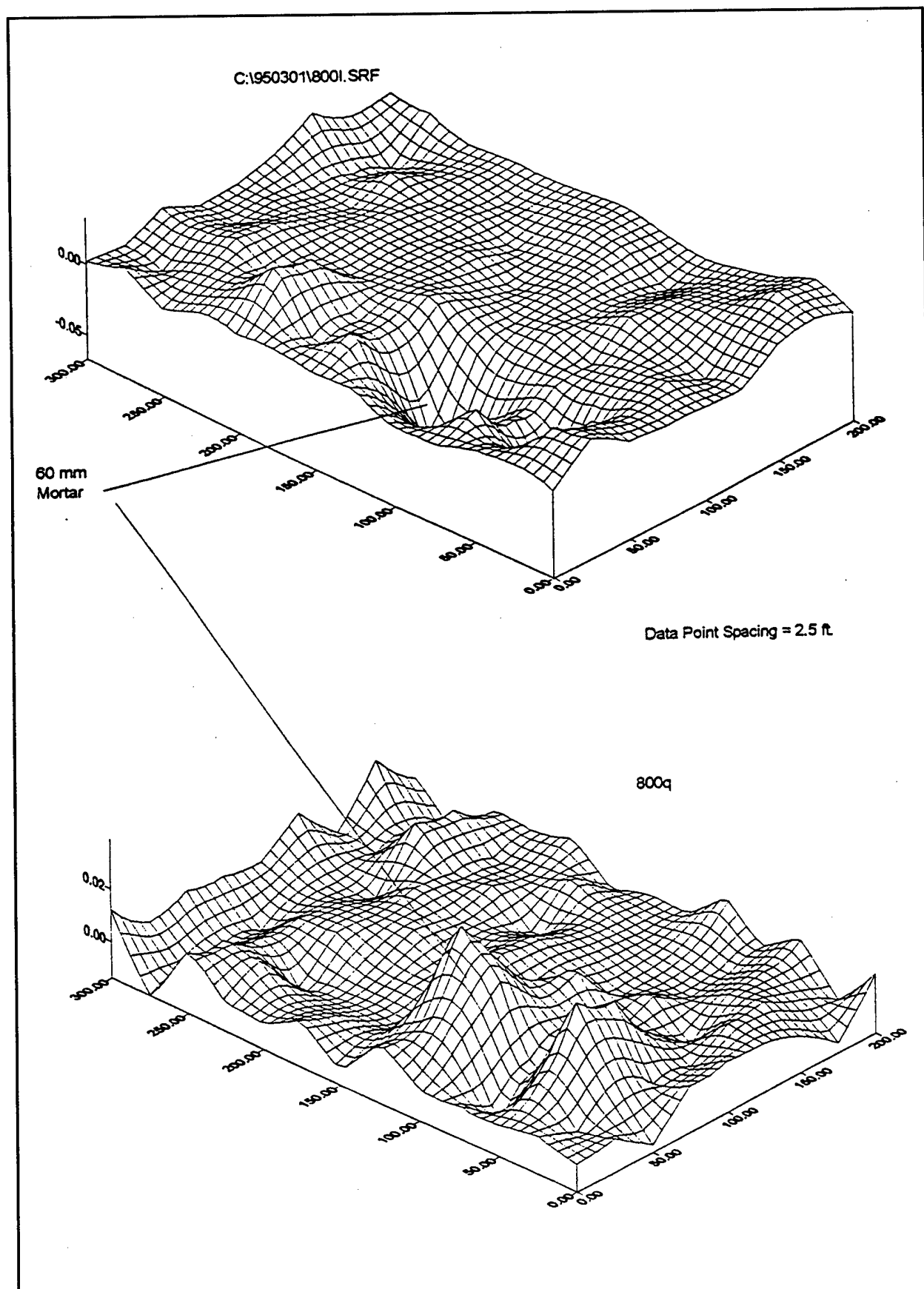


Figure 16. GEM-1 survey data for miscellaneous small munitions scattered on surface of search area.

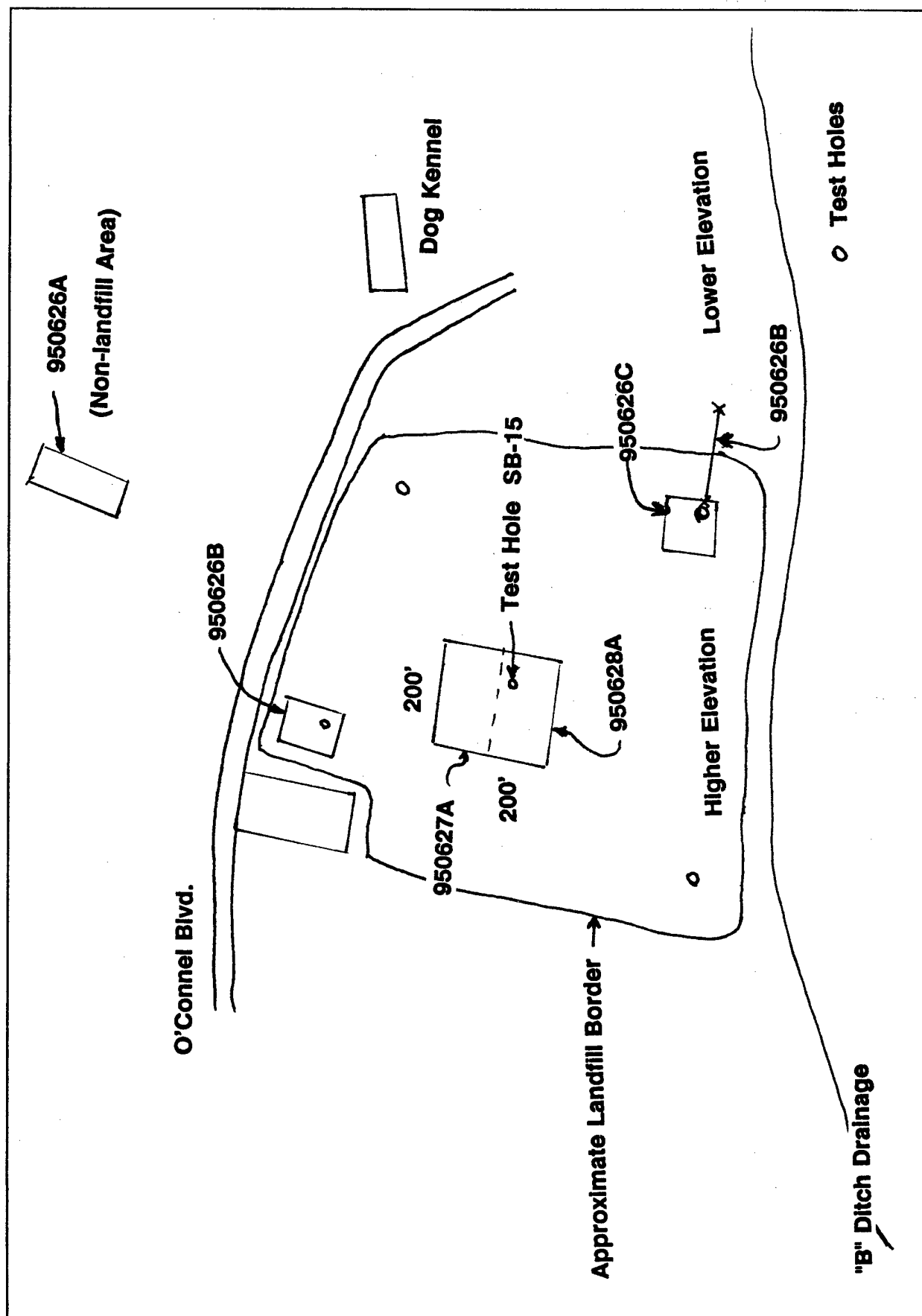


Figure 17. Fort Carson, CO, Landfill #5, approximate survey locations.

surveying techniques were used. Area surveys were conducted by staking out the perimeter of the search area, laying a tape measure across the ends of the search area, and placing a third tape along an edge of the search area. This tape was used to identify data points. Data were taken by walking with the GEM-1 along this tape and taking data every 10 ft. After the row of data was taken, the tape was repositioned into the search area 10 ft along the end tapes and another row of data was taken. This process was repeated until the complete search area had been covered. Layout and measurement was accomplished expediently with one person.

An area of  $200 \times 200$  ft was surveyed at 10-ft intervals in  $100 \times 200$  ft sections. Both surface and contour composite plots of the results are presented in Figure 18a. An independent contractor had made a number of test holes on the landfill location. The approximate locations are given on the sketch. The test hole contained within the 950626B search area was the only one in which papers and other trash objects appeared. One possible conclusion is that Area 1 of the surface plot contains primarily manure, while Area 2 consists of more conventional trash. The two areas are now separated by a road. Figure 18b plots the data from a single traverse that shows the edge of the landfill leading to Area 1.

### **P-47 Crash Site, Daykin, Nebraska**

During WWII a number of flight training bases were built in the Great Plains area from Texas north into Nebraska. The semi-arid conditions allowed flight training almost all year. In the summer of 1945, during training, a P-47 from the Bruning, NE Army Airfield collided with a passing B17. The B17 came down in pieces that remained on the surface. The P-47 buried itself at a location approximately 1 mile east of Daykin, NE. The farmer who had worked this acreage until 1993 identified the site where the P-47 came down. A  $100 \times 100$  ft area was surveyed using the GEM-1. A 10-ft grid point spacing was used on 3 July 1995. The survey was repeated on 2 December 1995 with 5 ft grid spacing. The in-phase data resulting from this survey are shown in Figure 19. The scale factors are included (without shading) to show the extent of data variation. This variation is quite small, but the similarity among the data from the three frequencies indicates the presence of small/deep targets. Small pieces of 1/4-in. plexiglass — possibly the P-47 windshield — were found in the survey area during both surveys.

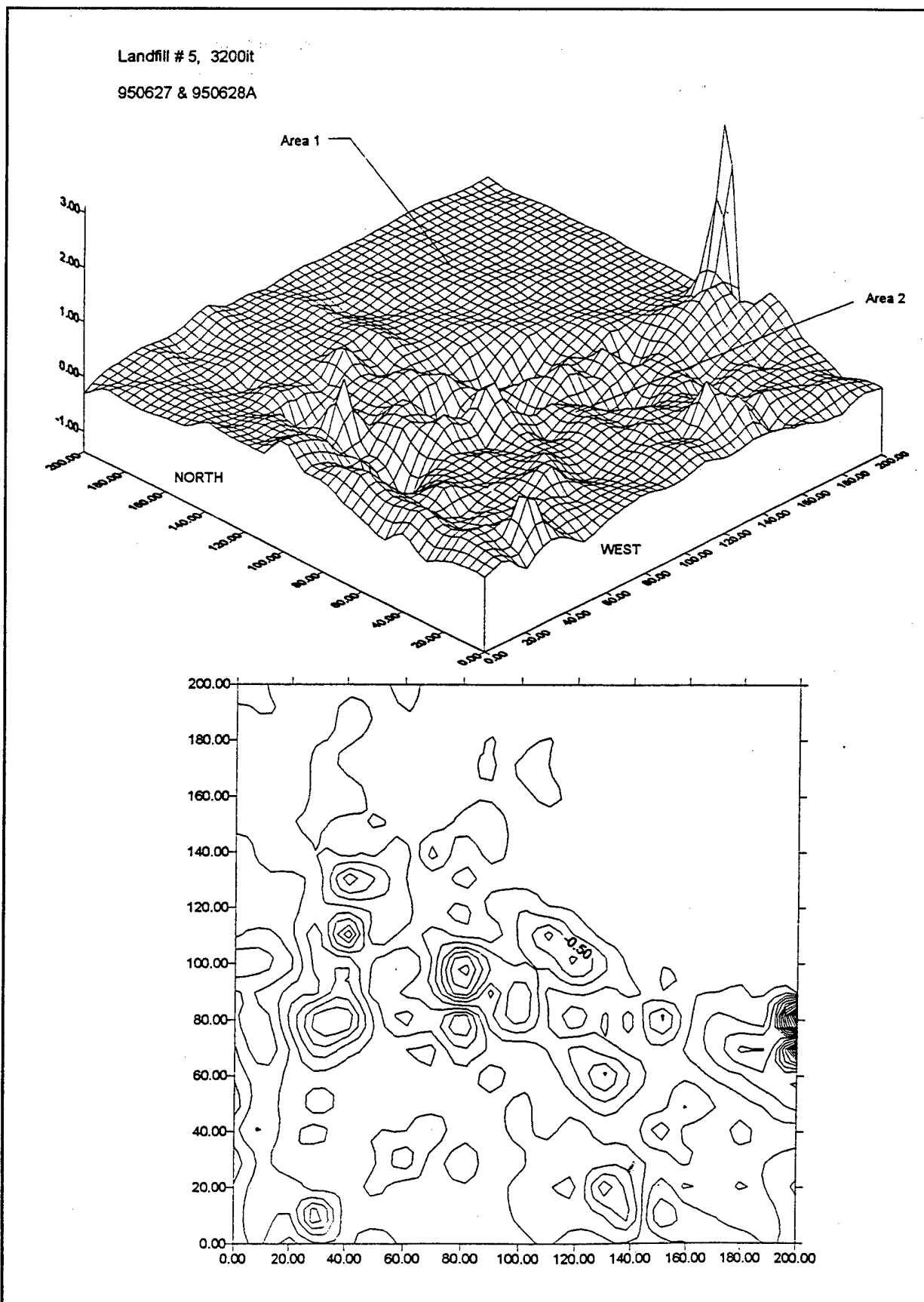


Figure 18a. Landfill #5 (partial), Fort Carson, CO.

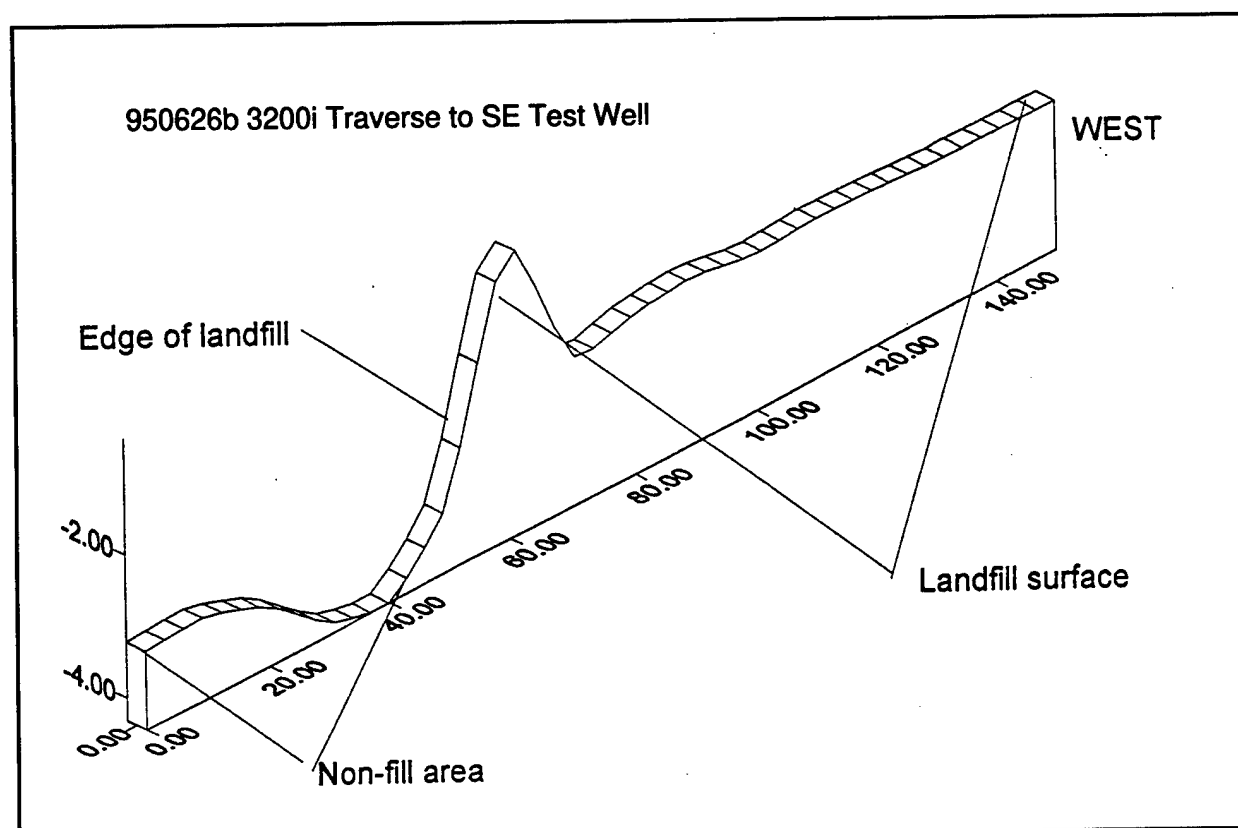


Figure 18b. GEM-1 survey at Landfill #5, Fort Carson, CO, 26 June 1995.

### Former Nike Antiaircraft Missile Base USTs

A large number of Nike anti-aircraft missile bases were built all over the United States during the late 1950s. Several of these sites were placed on Chicago Park District land, and some of the areas had previously been used for conventional anti-aircraft gunnery sites. Some of the tanks for generator diesel fuel and heating oil for buildings had been placed underground. After dismantlement in the early 1970s, the sites were returned to the Park District. No extant record of the fate of the underground tanks has been found. The Chicago District of the Corps of Engineers tasked USACERL to survey selected lake front areas near Montrose Harbor, Belmont Harbor, Burnham Park, and Jackson Park. The areas had been selected through examination of aerial photographs and existing site plans. Approximately 17 acres were surveyed. An additional small area on the Wolf Lake Recreation Area known to contain a tank, was surveyed. This site was particularly interesting due to the large amount of steel mill slag backfill over this area. Building foundations, floor slabs, and paved areas are still in place here. Nearly all evidence of the former use at the lake front sites had been removed. Most of the concrete demolition material from these sites seems to have been used as rip-rap on the Lake Michigan shore.



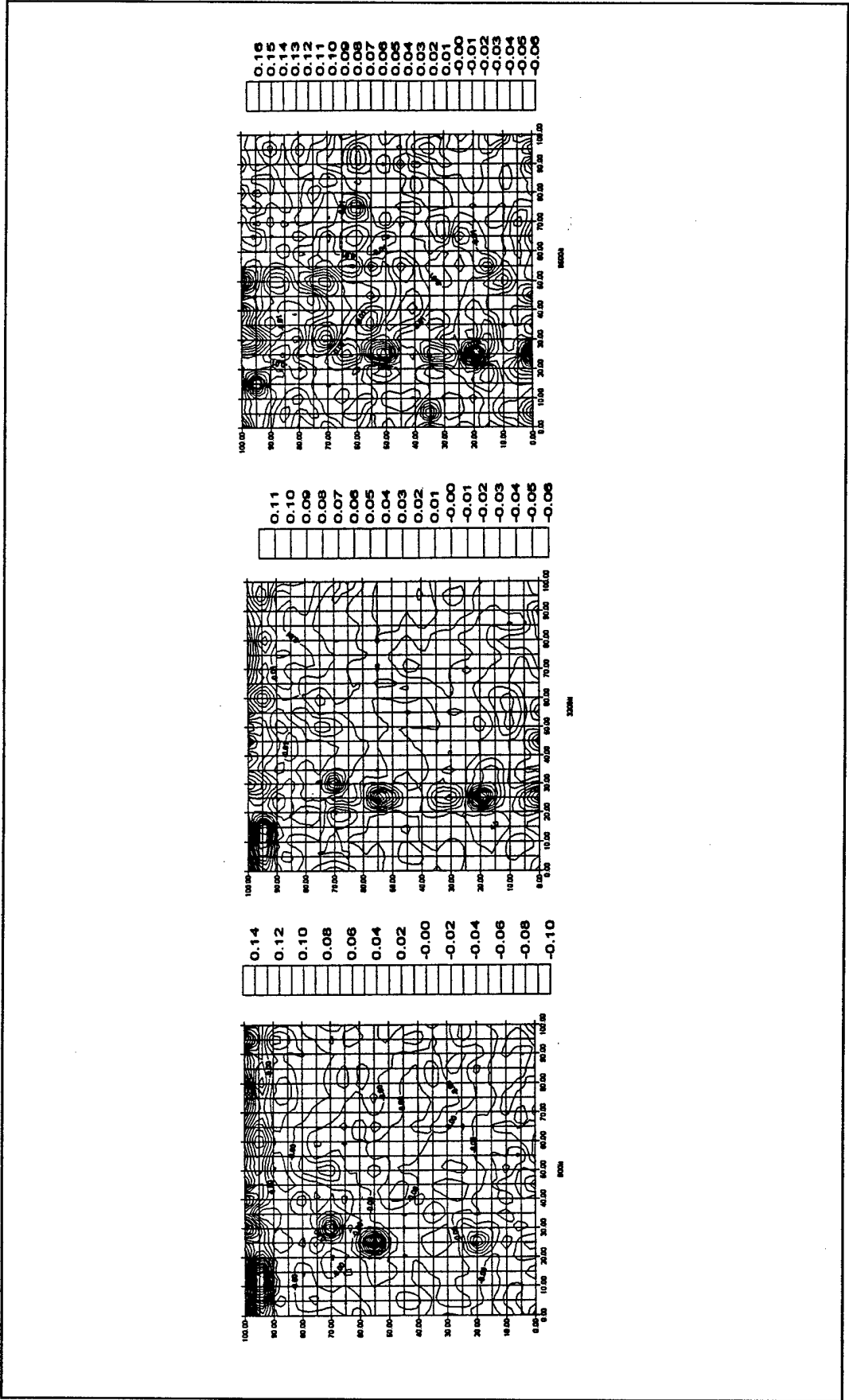


Figure 19. GEM-1 survey data, 1945 P-47 crash site, Daykin, NE, 951202t.

The results of the Wolf Lake survey are shown in Figure 20. The search area was identified by Chicago Corps of Engineers District personnel as containing a fuel tank for the nearby generator building location. The results of this survey demonstrated the effectiveness of the GEM-1 in locating buried objects and the plots illustrated an image of a probable tank. This was especially encouraging because the extensive coverage of the steel mill slag would make magnetometer data collected in this area particularly difficult to interpret.

Figure 21 is a recent aerial photograph of the Montrose Harbor search area. A mosaic built up of contour plots of the results of most of the surveys conducted in this area is shown in Figure 22. At least three large targets which are probable large storage tanks can be seen. Surveys of other Lake Shore areas resulted in a number of suspect targets, none of which seemed clearly to be tanks as seen at Wolf Lake and Montrose Harbor. One of these is shown in Figures 22 through 24. Most suspect targets were found near existing or historical roads.

Figure 24 shows a number of small-area, high-intensity targets associated with small bushes or trees in the park area. These "targets" were most likely the result of recent fertilizer applications in the near vicinity of this vegetation. Many other similar trees and bushes did not show comparable data perturbations. Fertilizer combining with moisture in the soil would tend to change the electrical conductivity of the soil.

### **Nebraska Farm Septic Tank, Tile Field, and 1-in. Pipe**

Experimental applications of the GEM-1 included a mapping of the leach field of a Nebraska farm septic system. The field mapped was thought to be composed of half tile installed in the early 1960s. A half tile system consists of a 2-ft wide trench with gravel in the bottom. This trench is covered with a half tile—a concrete half-cylinder with the open side facing down—then filled with soil. This survey was conducted in early December 1995. The results of this survey are shown in Figure 25. Temperatures were in the mid-40s (°F), and since the readings of the instrument appear to be subject to drift at cooler temperatures, an additional line of data was taken transverse to that shown in Figure 25. The data in Figure 26 shows that some of the apparent drift appears to be due to a change in soil conductivity across the survey area.

Figure 27 shows the data from a transverse path across a 1 in. water pipe buried 3 to 5 ft. This pipe has been in place since before the mid-1930s.

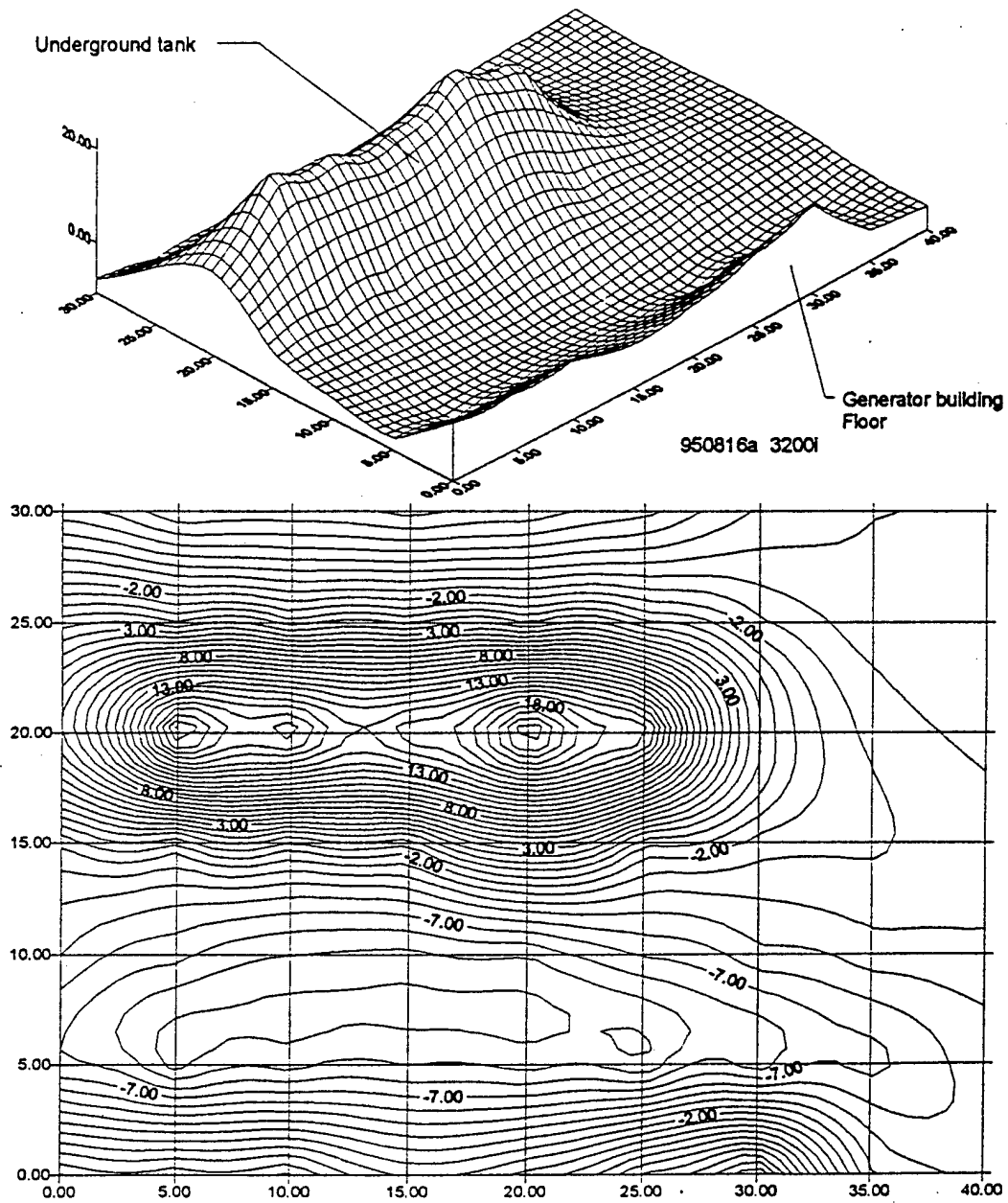


Figure 20. GEM-1 survey data, former Nike anti-aircraft missile base UST, Wolf Lake, Chicago, IL.



Figure 21. Aerial photograph of former Nike anti-aircraft missile site, Montrose Harbor, Chicago, IL, showing approximate search area.

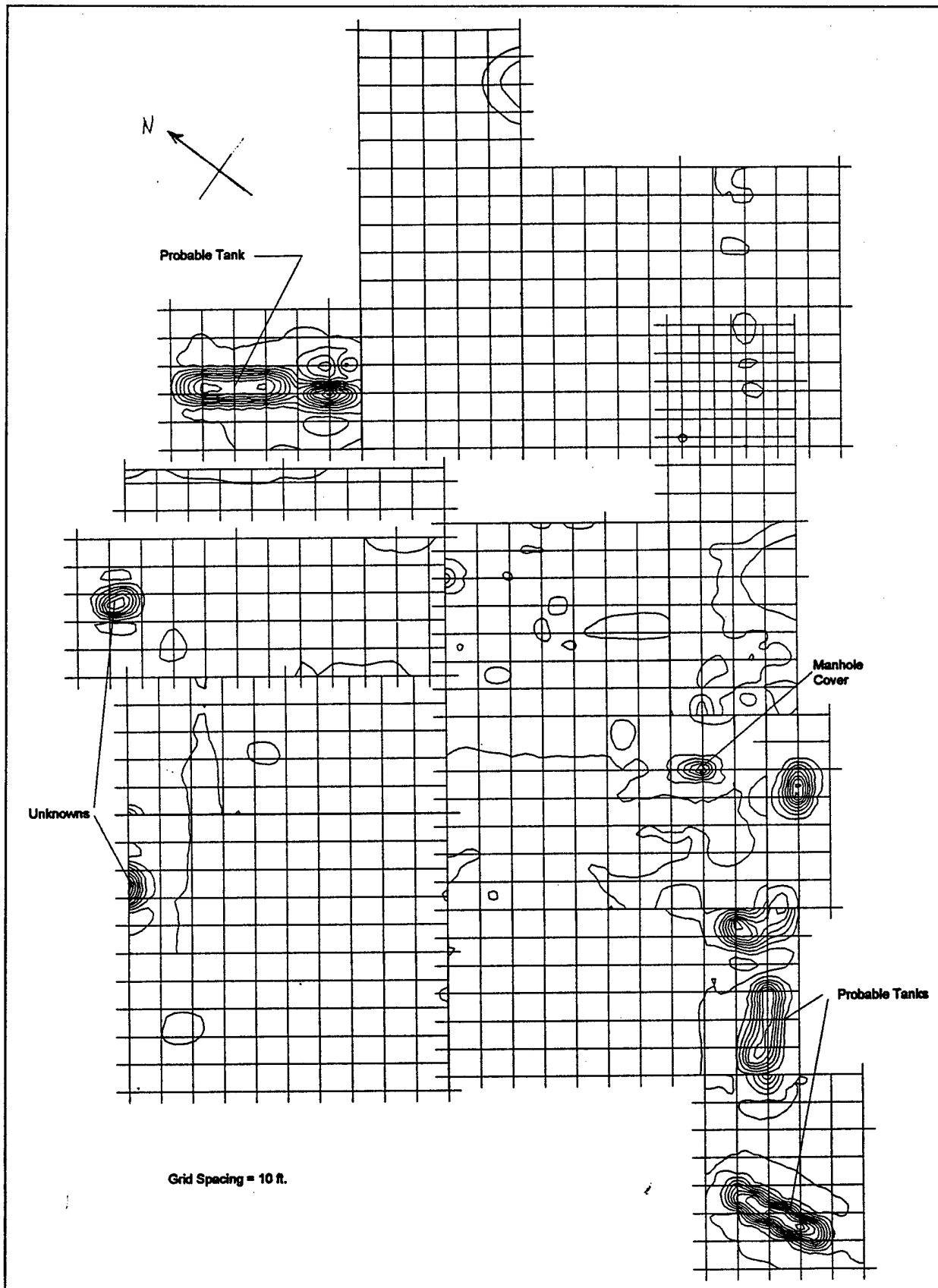


Figure 22. Composite contour plot of GEM-1 data of former Nike anti-aircraft missile site, Montrose Harbor, Chicago, IL, with multiple possible USTs.

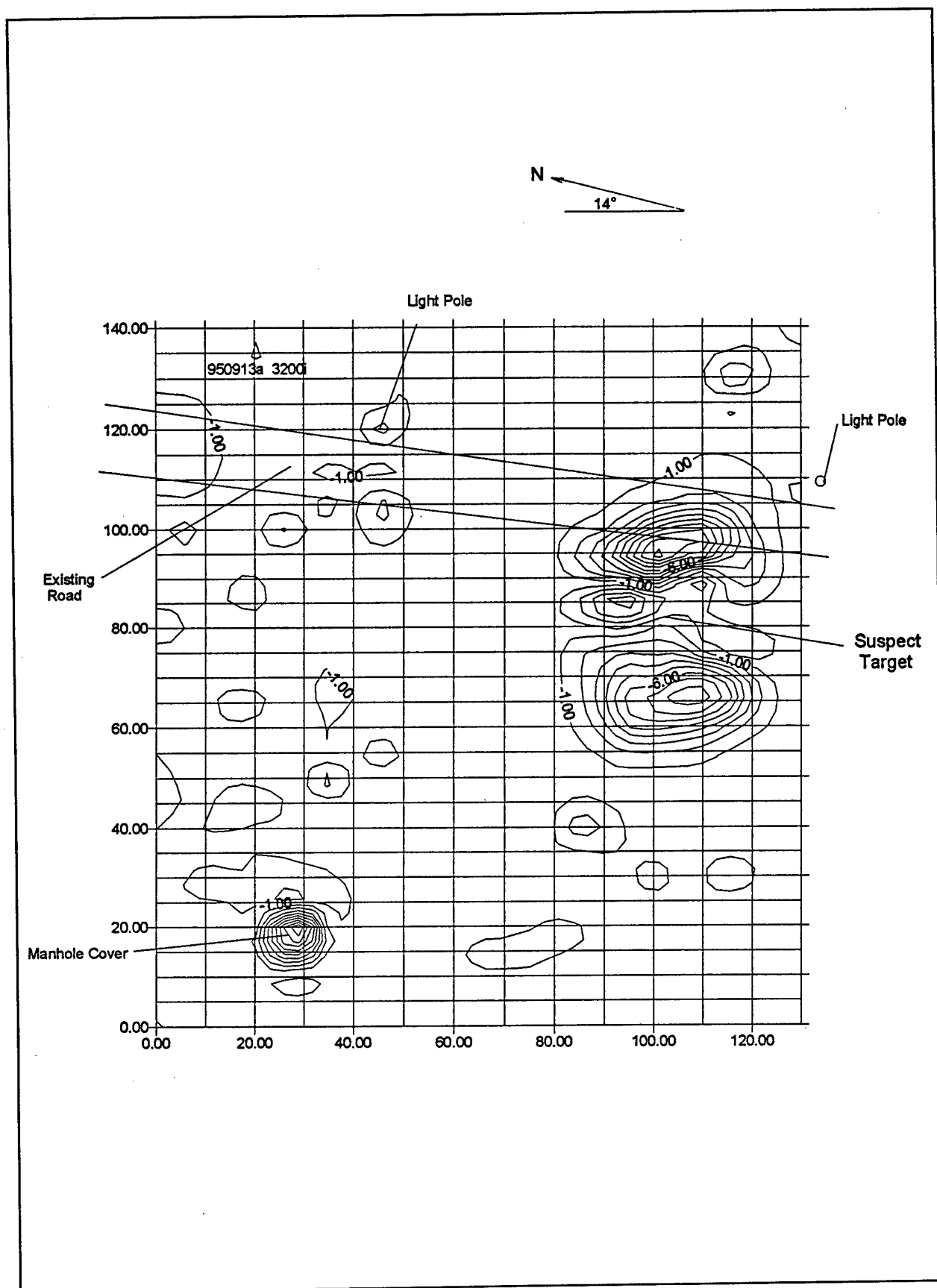


Figure 23. Former Nike anti-aircraft missile base, Promontary Point, Jackson Park, Chicago, IL, 9509131, 3200i.

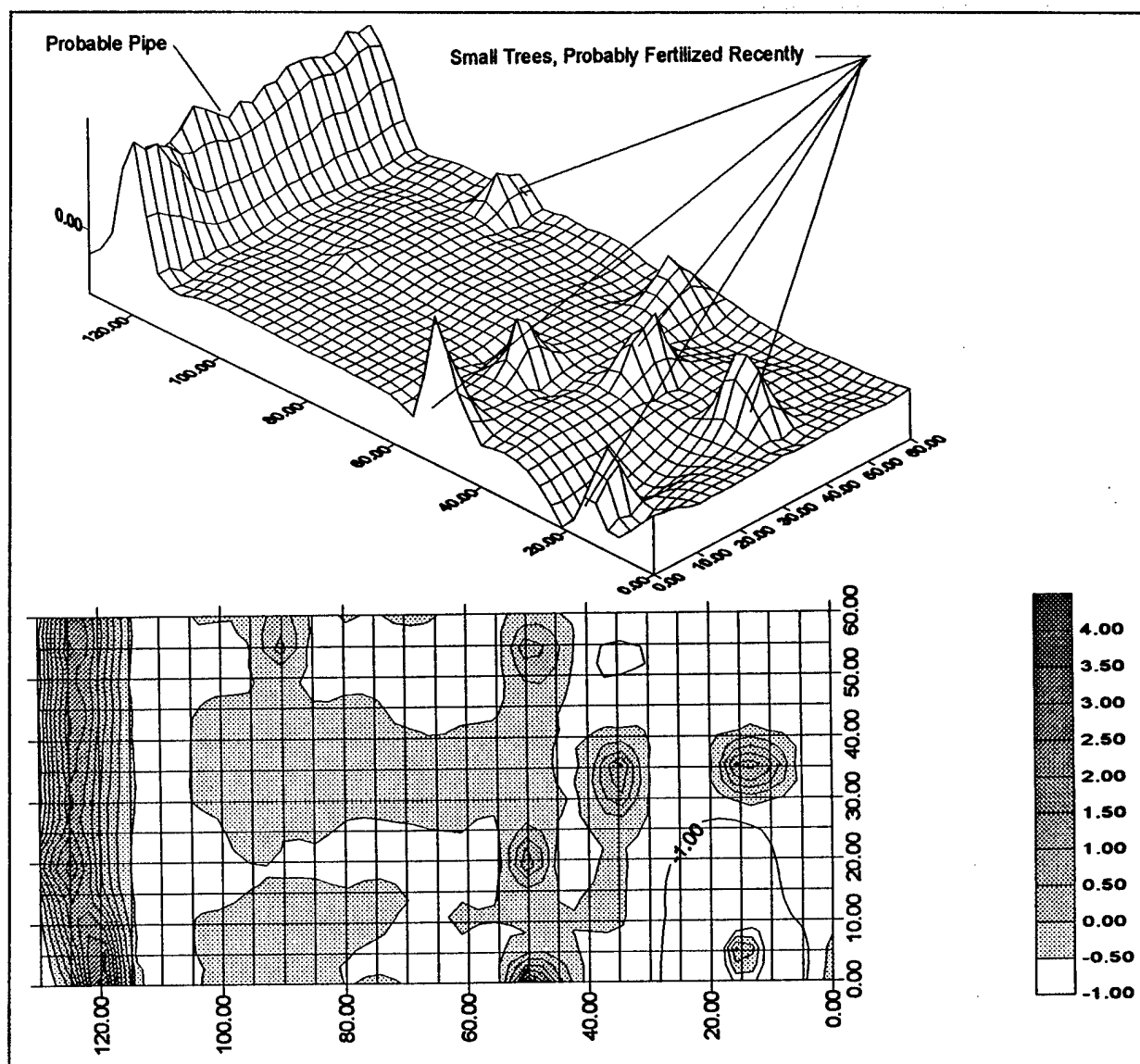


Figure 24. GEM-1 survey data, former Nike anti-aircraft missile base, Belmont Harbor, Chicago, IL.

## Enhanced Resolution Experiment

The experiment surveyed an area that contained an 18 in. square plate buried approximately 9 in. The plate is the shallower one described in the initial tests of the system conducted at USACERL in December 1993. This survey was conducted using a grid spacing of 1 ft to determine if shape information could be obtained from a smaller object. The location of the plate was determined by observing the GEM-1 readings with the operator moving around the approximate plate position. A 15 × 20 ft survey area was laid out to include the plate location. The survey method used three fiberglass tape measures placed on the ground, one along each end of the search area and a third along one side. The operator determined the data point

Rural Nebraska Septic System, 951203, 32001

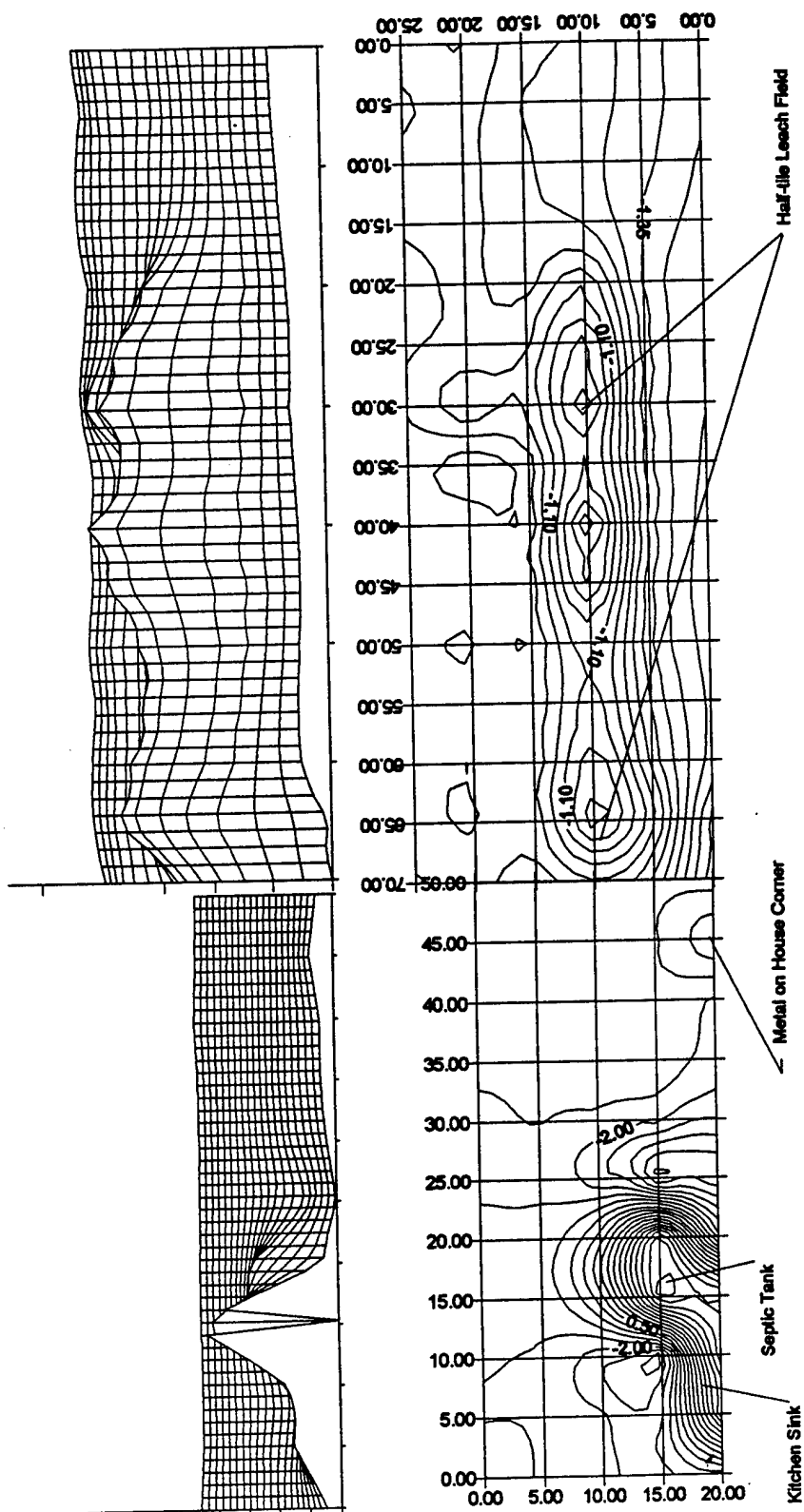


Figure 25. GEM-1 survey data, rural Nebraska septic system.



location by eyeballing the feet markings along this third tape as described in Chapter 3. The tape was moved in intervals of 1 ft across the search area after a row of data had been taken. No special procedures were used to assure accuracy, thus data point location accuracy could be from + or - 2 in. to 4 in. in each direction. Contour plots of the in-phase data are shown in Figure 28. Definite shape indications can be seen in these plots. The resolution obtained in this experiment seems to be limited by the geometry of the GEM-1 and the accuracy (location and angular position) possible with hand-held operation. Target size is somewhat more difficult to infer from the data. An approximate size can be derived, if one considers that primary zone of influence for the instrument is approximately the same as its physical dimensions. Approximate dimensions can be estimated by subtracting 3-4 ft from each side of the edge of the perturbation in data (as plotted on a contour plot) caused by the target.

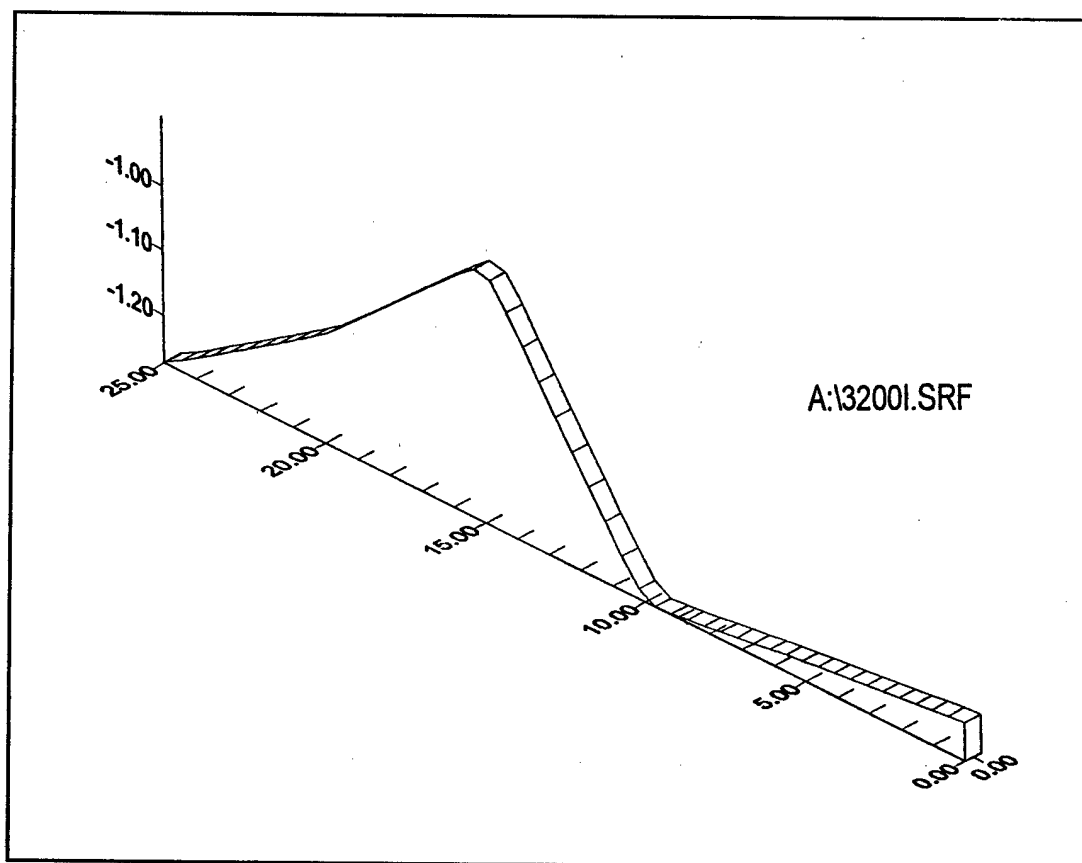


Figure 26. GEM-1 survey data of traverse of half-tile leach field.

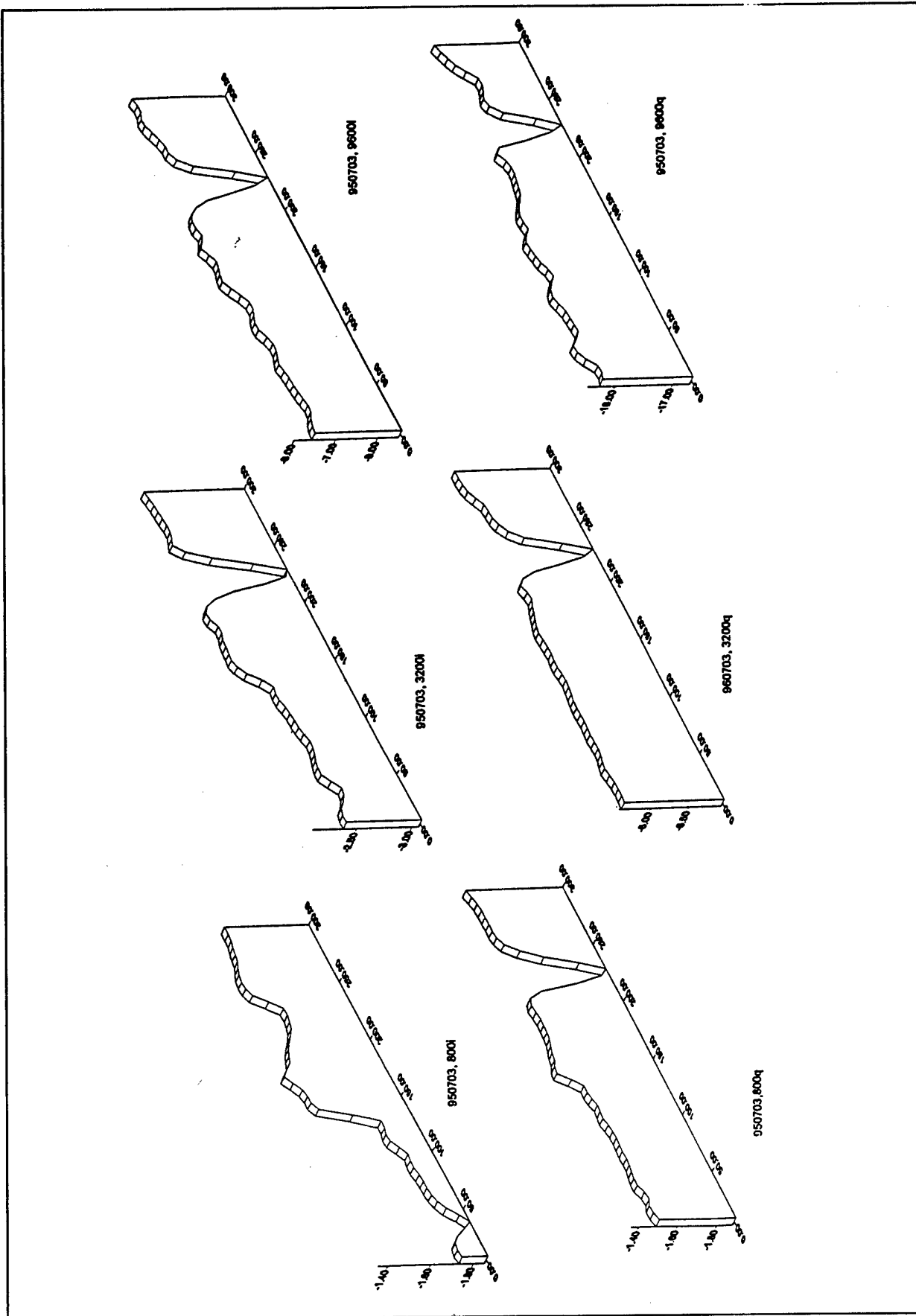
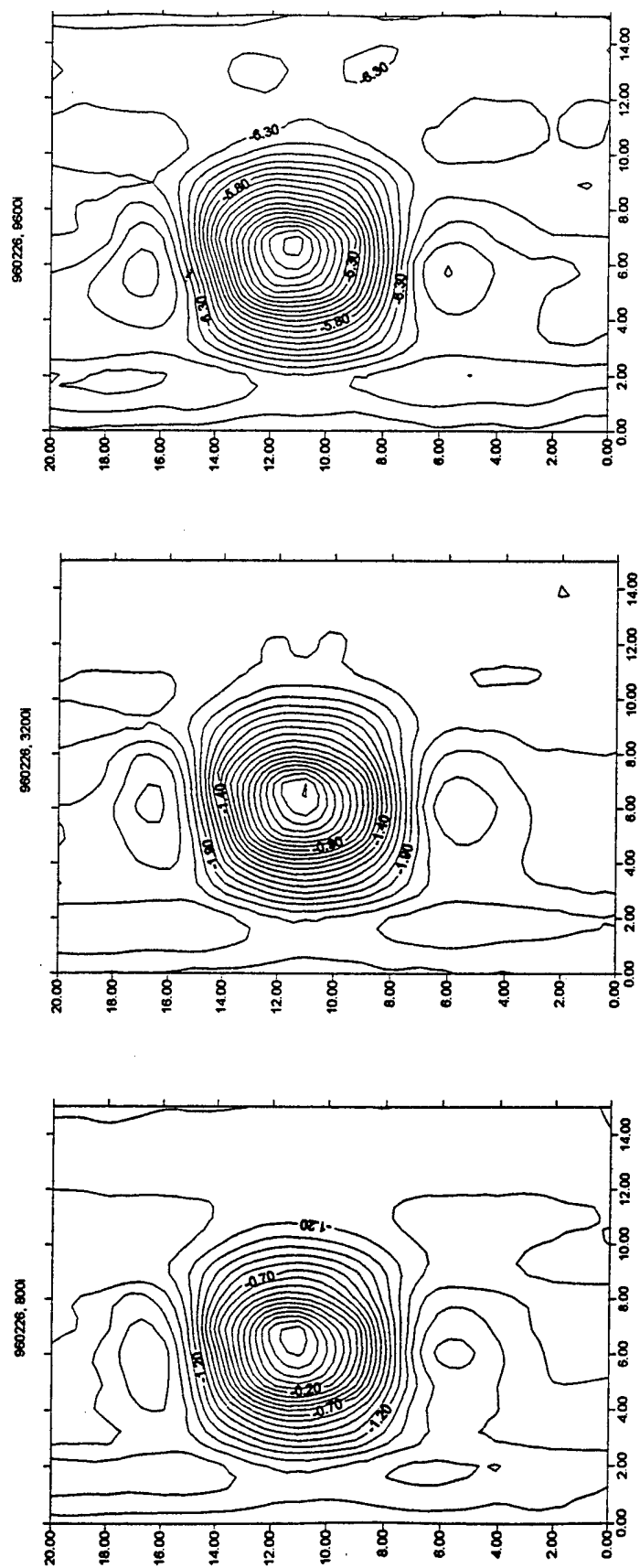


Figure 27. Traverse of a 1-in. water pipe.



**Figure 28. GEM-1 survey data, enhanced resolution experiment: target = 18 in. square aluminum plate, buried 9 in.; data point spacing = 1 ft.**

## 4 Cost Comparisons With Other Survey Systems

### GEM-1 and GEM-2

The advanced electromagnetics represented by the GEM-1 and GEM-2 technology tend to supplement rather than compete with other technologies for subsurface exploration. The data gathered by each system tends to be different. In addition, while it is difficult to claim accuracy related to costs of the application of an emerging technology, some general statements can be made. The commercial version of the GEM-2 (GEM-300) is expected to be available in the range of \$12,000–\$15,000. Labor associated with data gathering depends on the number of data points required, but a reasonable estimate, based on USACERL work and discussions with Geophex, is somewhere between \$500 and \$2,000 per acre for readily accessible open areas. In general, lower per acre costs should be possible with the GEM-2 given its capability for continuous data gathering that can greatly reduce the time required for conducting surveys. In most cases, the work can be done by one person.

USACERL can provide installation DPW users of GEM-type technologies with recommendations on survey design and equipment operation. Basic operation of the GEM-1 is relatively simple; the most complex part is downloading and processing the data, but as noted previously, data handling has been greatly simplified through the development of data-handling macros.

Most potential users of this technology probably would be better served by hiring a contractor to conduct surveys, as needed on occasion, rather than buying the GEM device and training personnel to use it. Any installation intending to purchase the commercial version of GEM would have to consider training costs as part of the total expenditure. Dedicated training would have to be arranged through the manufacturer.

Costs for other technologies are also quite variable, but again some general statements can be made. It must be remembered, however, that the data obtained

are different and there will be applications where a particular technology should be used due to its specific results.

## **Magnetometers**

Recording magnetometers are generally available at a variety of costs and capabilities. Labor for surveys appears to be quite similar to that required by the GEM-1/GEM-2 electromagnetic systems. Magnetometers, however, respond only to ferromagnetic materials and require a higher degree of skill for user interpretation of data. Magnetometer data are plagued by large numbers of false positives. The electromagnetic systems can also be expected to obtain useful data in some areas where magnetometers would be of limited use. Labor costs for the two systems should be quite similar. Geophex uses both systems for many of their surveys.

## **Earth-Contact Electrical Conductivity**

Earth-contact electrical conductivity measurement consists of operating a manual probe that uses two electrodes with 0.5 to 1.0 m separation. Readings are taken at fixed intervals. This technique requires access to the surface and a relatively clear survey area. It seems to have some archeological applications for shallow earth exploration (the depth of exploration is probably on the order of magnitude of the electrode separation). Equipment complexity is on the same order of the GEM systems. Time required for the surveys is probably slightly greater than that required by the GEM-1. In general, costs to conduct surveys with this technique will be higher than with the GEM-1/GEM-2.

## **Ground Penetrating Radar**

Ground penetrating radar (GPR) is rarely used in an area search mode, making direct cost comparisons difficult. It is considerably more complex, requires a greater degree of user interpretation of data, and is usually more labor intensive. Equipment cost is variable but likely to be in the \$30,000–\$60,000 range. Operation will probably require more than one person, so its cost to survey equal areas is expected to be considerably higher than the GEM-1/GEM-2. Electromagnetic system technology can be very useful in conjunction with GPR to reduce the total area necessary to be examined by the GPR.

## 5 Conclusions

USACERL's evaluation of the GEM-1 indicates that the instrument accomplishes its intended purpose well: expedient location of USTs. Unknown tanks were located and mapped at Building 180, Fort Riley, KS, and a known tank was mapped for Location C44, a former Nike anti-aircraft missile site. The first example was verified by excavation and the second was identified before the survey was conducted, both to document the appearance of a typical Nike tank and as an experiment for the operation of the GEM-1 in the steel mill slag backfilled area. The ease and clarity with which the data showed this tank were not expected because of the ferromagnetic properties of the backfill. Magnetometer technology would likely have had difficulty in this location. The significant number of possible tanks identified at the Montrose Harbor location remain to be verified.

Results of study using the USACERL test area indicated that the GEM-1 system had no difficulty locating the 18 × 18 in. aluminum plates but little success in locating the short lengths of small diameter buried pipes. Weather and frost conditions did not appear to cause significant variation in sensitivity. A slight increase in sensitivity was noted when the instrument was placed at the ground level for measurements when compared to the normal waist level operating height. However, ground-level placement of the instrument was accompanied by an apparent increase in the background noise level.

The technology shows significant potential for landfill mapping and characterization. Almost all types of fill will have a number of materials with electrical properties differing from the surrounding soil and will be relatively obvious in survey plots. Advanced versions of the instrument are designed for direct readout of soil conductivity, thus expanding the device's usefulness, especially for possible analysis of landfill materials.

Although the GEM-1 was not specifically evaluated for location and mapping of underground utilities, the serendipitous plotting of the underground electrical line (USACERL tests) and measurements with other metal pipe structures indicate that the instrument would work well for this application. In general, elevated power lines parallel to the long axis of the GEM-1 did not cause observable effects (at Fort Riley, Bldg. 180 and rural Nebraska roadsides).

A subject area not specifically addressed to a significant extent in the USACERL evaluation of this instrument was the capability to locate nonmetal targets. It was not possible to adequately judge the capability of the GEM-1 to locate fiberglass USTs in the Fort Riley surveys since it was not known for certain if a tank was located in the survey area. In addition, the effects of interfering structures would tend to overwhelm any variation in data because of the presence of fiberglass tanks. The historic ash pile in the residential back yard is an indication of potential applications for this instrument. Geophex, the SBIR developer of the system has used and is continuing to use their GEM-2 for a number of mapping applications of nonmetallic pollutants.

Large aboveground metallic objects located in any direction within a distance of 0 to 5 ft of the GEM-1 caused major perturbations in the data, from 5 to 10 ft gradually less. Such objects at distances greater than 10 ft did not seem to significantly affect the readings. Metallic objects above the surface of the earth tended to produce negative readings.

The downed airplane and landfill studies indicated that the resolution possible with the GEM-1 system was much better at 5 ft data point spacing than with the data points at 10 ft. The larger spacing can be useful for rapid site characterization and for identification of large targets since there will be approximately four times as many data points at 5 ft intervals. Geophex has developed the GEM-2 that has a considerably increased data gathering capability rate—up to an acre an hour with rows of data separated by 5 ft. Typical GEM-1 data gathering rates are from 250 to 300 points per hour. The approximate number of data points per acre is 1,850 for 5 ft spacing and 490 for 10 ft spacing

The enhanced resolution experiment indicates that the technology of the GEM-1 has potential for much improved imaging of subsurface objects. The maximum resolution obtainable is a function of sensor geometry and operator patience. A more compact sensor configuration would decrease the area examined for one data point, allowing an increased sensitivity and closer spacing of data points to increase the resolution.

Because the GEM-1 was designed specifically to detect USTs—relatively large targets—its geometry and sensitivity have not been optimized for smaller objects. Its utility for finding small objects such as unexploded ordnance will depend upon the size of the target. Additional research for sensor development and sensitivity improvement is required to expand the technology and apply it to small search subjects. This technology, with its simple operation, economical electronics,

portability, and high potential for accurate subsurface imaging, will find a prominent place in expedient subsurface exploration.

The GEM-1 is available through USACERL for limited demonstration projects. The GEM-300 is now available from Geophysical Survey Systems, Inc. for \$13,900, and will likely see significant use by geophysical surveying enterprises.



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ATTN: CEMP-R  
ATTN: CERD-C  
ATTN: CERD-ZA  
ATTN: CERD-L  
ATTN: CERD-M  
ATTN: CERM  
ATTN: DAEN-ZC  
ATTN: DAIM-FDP

CECPW 22310-3862  
ATTN: CECPW-E  
ATTN: CECPW-FT  
ATTN: CECPW-ZC

US Army Engr District  
ATTN: Library (40)

US Army Engr Division  
ATTN: Library (11)

US Army Europe  
ATTN: AEAEN-EH 09014  
ATTN: AEAEN-ODCS 09014  
29th Area Support Group  
ATTN: AEUSG-K-E 09054  
222d BSB Unit #23746  
ATTN: AETV-BHR-E 09034  
235th BSB Unit #28614  
ATTN: AETV-WG-AM 09177  
293d BSB Unit #29901  
ATTN: AEUSG-MA-E 09086  
409th Support Battalion (Base)  
ATTN: AETTG-DPW 09114  
412th Base Support Battalion 09630  
ATTN: Unit 31401  
221st Base Support Battalion  
ATTN: Unit 29623 09096  
CMTG Hohenfels 09173  
ATTN: AETTH-SB-DPW  
Mainz Germany 09185  
ATTN: AETV-MNZ-E  
21st Support Command  
ATTN: DPW (8)  
SETAF  
ATTN: AESE-EN-D 09613  
ATTN: AESE-EN 09630  
Supreme Allied Command  
ATTN: ACSGEB 09703  
ATTN: SHIHB/ENGR 09705

INSCOM  
ATTN: IALOG-J 22060  
ATTN: IAV-DPW 22186

USA TACOM 48397-5000  
ATTN: AMSTA-XE

Defense Distribution Region East  
ATTN: ASCE-WI 17070-5001

Defense Distribution Region West  
ATTN: ASCW-WG 95296-0100

HQ XVIII Airborne Corps 28307  
ATTN: AFZA-DPW-EE

4th Infantry Div (MECH) 80913-5000  
ATTN: AFZC-FE

US Army Materiel Command (AMC)  
Alexandria, VA 22333-0001  
ATTN: AMCEN-F  
Installations: (20)

FORSCOM  
Forts Gillem & McPherson 30330  
ATTN: FCEN  
Installations: (20)

6th Infantry Division (Light)  
ATTN: APVR-DE 99505  
ATTN: APVR-WF-DE 99703

TRADOC  
Fort Monroe 23651  
ATTN: ATBO-G  
Installations: (20)

Fort Belvoir 22060  
ATTN: CETEC-IM-T  
ATTN: CETEC-ES 22315-3803  
ATTN: Water Resources Support Ctr

USA Natick RD&E Center 01760  
ATTN: STRNC-DT  
ATTN: AMSSC-S-IMI

US Army Materials Tech Lab  
ATTN: SLCMT-DPW 02172

USARPAC 96858  
ATTN: DPW  
ATTN: APEN-A

SHAPE 09705  
ATTN: Infrastructure Branch LANDA

Area Engineer, AEDC-Area Office  
Arnold Air Force Station, TN 37389

HQ USEUCOM 09128  
ATTN: ECJ4-LIE

AMMRC 02172  
ATTN: DRXMR-AF  
ATTN: DRXMR-WE

CEWES 39180  
ATTN: Library

CECRL 03755  
ATTN: Library

USA AMCOM  
ATTN: Facilities Engr 21719  
ATTN: AMSMC-EH 61299  
ATTN: Facilities Engr (3) 85613

USAARMC 40121  
ATTN: ATZIC-EHA

Military Traffic Mgmt Command  
ATTN: MTEA-GB-EHP 07002  
ATTN: MT-LOF 22041-5000  
ATTN: MTE-SU-FE 28461  
ATTN: MTW-IE 94626

Fort Leonard Wood 65473  
ATTN: ATSE-DAC-LB (3)  
ATTN: ATZT  
ATTN: ATSE-CFLO  
ATTN: ATSE-DAC-FL  
ATTN: Australian Liaison Office

Military Dist of WASH  
Fort McNair

ATTN: ANEN-IS 20319

USA Engr Activity, Capital Area  
ATTN: Library 22211

US Army ARDEC 07806-5000  
ATTN: AMSTA-AR-IMC

Engr Societies Library  
ATTN: Acquisitions 10017

U.S. EPA, Region V  
ATTN: AFRC-ENIL-FE 60561

U.S. Army Environmental Center  
ATTN: SFIM-AEC-NR 21010  
ATTN: SFIM-AEC-CR 64152  
ATTN: SFIM-AEC-SR 30335-6801  
ATTN: AFIM-AEC-WR 80022-2108

Defense Nuclear Agency  
ATTN: NADS 20305

Defense Logistics Agency  
ATTN: MMDIS 22060-6221

National Guard Bureau 20310  
ATTN: NGB-ARI

US Military Academy 10996  
ATTN: MAEN-A  
ATTN: Facilities Engineer  
ATTN: Geography & Envr Engrg

Naval Facilities Engr Command  
ATTN: Facilities Engr Command (8)  
ATTN: Division Offices (11)  
ATTN: Public Works Center (8)  
ATTN: Naval Constr Battalion Ctr  
93043  
ATTN: Naval Fac Engr Serv Ctr  
93043-4328

8th US Army Korea  
ATTN: DPW (11)

USA Japan (USARJ)  
ATTN: APAJ-EN-ES 96343  
ATTN: HONSHU 96343  
ATTN: DPW-Okinawa 96376

416th Engineer Command 60623  
ATTN: Gibson USAR Ctr

US Army MEDCOM  
ATTN: MCFA 78234-6000  
Fitzsimons AMC 80045-5000  
ATTN: MCHG-PW  
Fort Detrick 21702-5000  
ATTN: MCHS-IS  
Fort Sam Houston 78234-5000  
ATTN: MCFA-PW  
Walter Reed AMCenter 20007-5001  
ATTN: MCHL-PW

Tyndall AFB 32403  
ATTN: HQAFCEA/CES  
ATTN: Engrg & Svc Lab

USA TSARCOM 63120  
ATTN: STSAS-F

American Public Works Assoc. 64104

US Army CHPPM  
ATTN: MCHB-DE 21010

US Gov't Printing Office 20401  
ATTN: Rec Sec/Deposit Sec (2)

Nat'l Institute of Standards & Tech  
ATTN: Library 20899

Defense General Supply Center  
ATTN: DGSC-WI 23297-5000

Defense Construction Supply Center  
ATTN: DCSC-WI 43216-5000

Defense Tech Info Center 22060-6218  
ATTN: DTIC-O (2)

280  
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